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THE COMPOUND LOCOMOTIVE OF THE RHODE ISLAND LOCOMOTIVE WORKS, PROVIDENCE, R. I.

[*Report of the Committee on Science and the Arts, with Appendices.*]

[No. 1,610.] HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 30, 1892.

The sub-committee of the Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania, to whom was referred, for examination,

THE COMPOUND LOCOMOTIVE OF THE RHODE ISLAND LOCOMOTIVE WORKS.

Report, That in order to set forth the merits of this invention it has had submitted to it a record of a series of tests made under the supervision of Mr. C. H. Batchellor, chief draughtsman of said works, together with copies of

diagrams and descriptions of the engines under test, which records accompany this report, and are as follows:

The engines are of a type known as two-cylinder compounds; that is, such as use the steam first in a small or high-pressure cylinder, on one side of the engine, and exhaust through a connecting pipe, within the smoke box, into the steam chest of a larger low-pressure cylinder on the other side, in which cylinder the steam is further expanded and from which it is finally exhausted through a blast pipe into the chimney in the usual way.

To this connecting pipe or receiver, between the two cylinders, is joined (forming part of the same) an automatic intercepting valve, to which is also attached an automatic differential pressure-reducing valve, an exhaust valve, and a controlling valve worked by hand in the cab. The valves constitute the essential features of this invention.

The object of this invention is to provide means whereby the engine may be started and run continuously with steam directly from the boiler, in both cylinders, each doing half the work, and each exhausting into the stack and atmosphere directly. At the will of the engineer the engine may be changed into compound-working, these valves and steam-ways being designed to effect this object automatically, according as the engineer moves the lever connected with the controlling valve.

These improvements are the invention of Mr. C. H. Batchellor, and patented by him September 22, 1891, full specifications of which accompany this report.

The operation and effects of the intercepting valve and its auxiliaries may be described as follows:

This valve being in any position and the throttle being opened, boiler steam will pass to the high-pressure cylinder in the usual manner, and also through a branch pipe to the intercepting valve, into the space between the two smaller pistons fixed on one end of the valve stem, causing the pistons to move from this end towards the larger of the two pistons, by which communication for steam is established through the inter-piston space to a pipe leading through an automatic reducing valve, and thence into the low-pressure

steam chest, the pressure being reduced from any existing boiler pressure in the ratio of the cylinder areas. This position of the intercepting valve closes the low-pressure steam chest against a flow of steam from the receiver.

The three pistons on the valve-stem of the intercepting valve are so proportioned that they will automatically change to the compound position, when the pre-determined pressure in the receiver has been reached by exhausts from the high-pressure cylinder; the engine thus starts with steam in both cylinders and automatically changes to compound at a desired receiver pressure.

The engine may be changed from the compound system to the simple at any time, at the will of the engineer, by opening a valve connecting the receiver to the exhaust pipe, allowing the exhausts of the high-pressure cylinder to be ejected through the exhaust nozzles in the usual manner. The operation of this exhaust valve permits receiver pressure to enter the smaller end of the piston chamber of the intercepting valve, in order to insure the movement of the piston to that necessary to permit the boiler steam to enter the low-pressure cylinder, and close the receiver against the same, and to do this before the receiver is emptied through the exhaust.

This insures against a lapse of continuous action in the low-pressure cylinder, during the change from the compound to the simple system while running.

It is obvious that, in case of bad conditions of starting, the engine may be operated as a simple one at the will of the engineer, by opening the exhaust valve before starting, and that upon its closure the pistons will automatically take the compound position as already described.

The motions of this intercepting valve are controlled by a fluid piston brake, so that it cannot be moved except by a force superior to the fluid resistance, which the steam supplies, and it is inert wherever placed.

This engine differs from all other two-cylinder compound locomotives in this country, in having a means vided by which the engine may be worked just as a simple engine is, with an independent exhaust from each cylinder

This arrangement provides sufficient power at starting and under any condition of service for a period of time, or a distance from the starting point, which is at the will of the engineer.

This type of compound can be run as a simple engine in case of break-downs, with no more trouble than an ordinary engine.

In point of cleanliness, *i. e.*, freedom from cinders and black smoke, the compound offers a marked contrast to the simple engines.

The fastest and hardest work has called but for the most ordinary care in the lubrication of parts; one of them on trial (called No. 2600), has never shown a suggestion of heating in any of the bearings or journals, all of which are of the ordinary size, and this engine has so satisfactorily met all the requirements of heavy and fast express service that have been placed upon it for several consecutive months, that the builders believe themselves justified in claiming as a conservative estimate a saving of fifteen to twenty-five per cent. of fuel, in express service, in competition with a simple locomotive, the amount of saving depending upon the service.

These improvements can be applied to existing simple locomotives.

The slide valves are operated by Stephenson's link as applied to locomotives generally.

The possibility of using this engine as a simple one indefinitely, is also a very desirable adjunct for yard work, or short runs with many stops.

As an illustration of the softness of the blast, due to the low tension of the escaping steam after continued expansion in both cylinders, the engine practically throws no sparks during the hardest service, even with a clear passage from the boiler tubes to the atmosphere.

The application of steam power to the bearings of a compound engine is more evenly distributed than in simple ones, as is well known, which must contribute to smooth and easy running in a locomotive. This effect is apparent in the several graphical illustrations shown in this report,

which speaks largely in favor of better stress effects when compared with the performance of the simple engine in same service.

We have here the most scientific development of a two-cylinder compound engine, automatically adapted to all requirements of variable service.

Your sub-committee, having examined the mechanisms and applications of these improvements in detail, as well as all the disinterested records of the same at its command, and having carefully noted and compared the devices and claims therefor, of other inventions for a like purpose, concludes this report by recommending the award of the ELLIOTT CRESSON MEDAL to Mr. C. H. Batchellor, for his invention.

JOHN H. COOPER, *Chairman,* H. R. HEYL,
JOHN E. CODMAN, H. F. COLVIN,
LUTHER L. CHENEY.

Adopted, February 24, 1892.

ARTHUR BEARDSLEY,
Chairman of the Committee on Science and the Arts.

APPENDIX I.

COMPOUND LOCOMOTIVE OF THE RHODE ISLAND LOCOMOTIVE WORKS, PROVIDENCE, R. I.

In the following pages is given a description of the mechanism employed in the operation of the two-cylinder compound locomotives, built by the Rhode Island Locomotive Works; also the data and results of comparative tests regarding the economy and general efficiency of these locomotives as compared with ordinary locomotives, in the following services, each contained in a section of the folio.

SECTION 1.—ELEVATED SERVICE.

Gives the data and results of a comparative test between two locomotives in elevated railroad service; the compound locomotive being a duplicate of the simple one with new cylinders.

SECTION 2.—EXPRESS PASSENGER SERVICE.

Gives the data and results of comparative tests between different simple locomotives and a compound locomotive built by the Rhode Island Locomotive Works for fast express service.

Serious doubts having been commonly expressed as to the ability of the compound to cope advantageously with these two classes of service, this folio is prepared as the most concise and complete method by which the numerous questions concerning actual results can be answered. All results are from data verified by the respective railroad companies.

SECTION 1.—ELEVATED SERVICE.

Description of Engines.

The engines compared are No. 62 Simple and No. 58 Compound, of the Brooklyn and Union Elevated Railroads of Brooklyn, N. Y. (A synopsis of sizes is given in Table 1.) Both engines were of the Forney type, having two pairs of connected driving wheels, with a four-wheeled, trailing, swing truck supporting the tank, the whole connected to a rigid frame. This design is used to run forward or backward at will.

The compound engine was a simple engine rebuilt by the Rhode Island Locomotive Works, so far as the cylinders and their appurtenances are concerned, and is of the two-cylinder type, the cylinders being connected by a copper receiver. The cylinder sizes of the compound were designed to do the average service work, so near as it could be judged, with the best economy. The limitations which the size of compound cylinders, designed for this effect, must necessarily bring upon the starting, or even the hauling power of the engine under exceptionally severe conditions, is recognized and provided for by a device allowing the engine to be run at will as a simple engine: the steam pressure in the low-pressure cylinder being reduced from that in the high-pressure cylinder in direct ratio of the

piston areas, irrespective of the boiler pressure. This allows the compound to be used as a simple engine, and greatly increases its maximum power; this becomes necessary in emergency cases only. The possibility of using the engine as a simple engine indefinitely is also a very desirable adjunct for yard work, allowing the engine to be worked to much better advantage. In ordinary circumstances the engine starts from rest as a simple engine, with direct steam in both cylinders, the cylinders having equal power. When the normal pressure in the receiver is reached, by means of the exhaust from the high-pressure cylinder, the direct steam is automatically cut off from, and the receiver steam admitted into, the low-pressure cylinder, and the engine thus thrown into the compound system. There is thus no appreciable change in power when the change from simple to compound is made, either in changing automatically or on being changed from the cab. The automatic change occurs from one-half to one revolution of the drivers. For actual performance in this respect see indicator cards, *Plates XXIII* and *XXVII*, inclusive.

SERVICE.

The service for which the engines under consideration were designed is of a severe nature for locomotives of ordinary form, and is considered much more so for a compound locomotive, being a series of starts and stops in quick succession, the profile containing many grades and sharp curves; prompt running time being indispensable. The total length of the division on which the engines were run is five miles, divided into sixteen passenger stations and two junction stations, at which stops were required at the time the compound was run on account of a rule issued between October 15th and November 24th. Trains consist of two cars during the middle of the day and late at night, and three or four cars during morning and evening hours. The running time is twenty-four minutes, with a headway of six minutes between trains during the two-car trips and five minutes during the four-car trips. See Table 2 for the number of cars hauled each trip, and the running time each day of the test.

CONDITIONS OF TEST.

The compound engine was run November 24, 1890; the simple, October 15, 1890. The engines were started from the yard at East New York at 6.15 A.M., and run six miles, with a light four-car train, to Fulton Ferry, where they commenced service, making twenty-two trips (eleven round trips) of five miles each, from Fulton Ferry to Ridgewood and return; then one trip of four empty cars to East New York, six miles, making a total train mileage of 122 miles from 6.15 A.M. to 8 P.M. The running time was kept by one watch, time being taken at each terminal; the duration of stops at regular and signal stations was not taken. They averaged about the same, both days being pleasant, the rail good, and the locomotives under trial not being held at signal stations to any unusual extent. The trip at 6.12 P.M., on November 24th, however, was an exception, trains being delayed seven minutes in the busiest part of the day, by awaiting the movements of an extra engine. This necessitated the hand-

ling of the exceptionally large number of passengers who had congregated, and required extra time at stations.

CONDITION OF ENGINES.

Simple engine No. 62, together with its crews, was selected by the railroad company as being the most economical on the road, as judged by performance sheets and competitive trials. The engine seemed in good condition, with the exception of the safety-valve, which leaked enough to show steam to a limited extent. The blow-off cock also leaked water; this was measured and accounted for.

Compound engine No. 58 had new metallic packing and leaked badly at the left valve stem. The throttle also leaked considerably.

MANIPULATION OF THE ENGINES AND PERSONS CONCERNED.

The crew who handled the simple engine were Mr. James Giles, engineer, and S. A. Sampson, fireman. These men formed part of the double crew who had handled it from the time it came on the road, and together with the other crew had demonstrated their expertness in economic running. Mr. Giles being off duty, the compound was handled by Mr. H. N. Fessenden, who ran in conjunction with Mr. Giles on the simple engine. Mr. Sampson did the firing. The management of the engines left nothing to be desired. The compound had been in their hands about ten days before the test was made, and was run entirely by the reverse lever until the first notch was reached, the throttle being kept wide open. The blower was used but once or twice on the compound, and sparingly on the simple. No. 58 was always worked compound automatically while in service.

COAL CONSUMPTION.

Weighed coal was used as follows: A new fire was used on both days, the tank was cleaned and weighed coal put in. The fire was built the night before and banked from coal outside the tank. When the fireman fixed his fire for running about 5.30 A.M., he used coal out of the tank, and continued so to do until the yard was reached at 8 P.M., when the condition of the fire was noted and the coal left in the tank weighed back. The state of the fire and steam pressure was similar each day at time of using first weighed coal. Each bucket of coal was weighed by an employé of the Railroad Company. It was all of the same quality and was free from dirt. The size of the coal was broken lump, and was of a soft anthracite quality. The coal was not wet during the test. The fire was well burned out at the end of each day, especially so on October 15th. The ashes were not weighed, circumstances not admitting of it. They showed a very small per cent. of unburnt coal each day. The compound burned its fires with a light draft on all trains. Steam was made very freely, the door being on the latch frequently, even with heavy trains, and especially so with light trains. Engines of the simple class steam freely with a light fire on light trains, but on the three and four-car trains the blast is sharp and fires heavy in order to keep up steam. The compound makes steam with a draft so light and even that it would seem able to

burn pea coal with good steaming results, and a further saving in fuel expense. The quality of coal used breaks up immediately on contact with fire; and on regular engines quite an item is lost through the stack in a bright, unburnt condition, in small particles. Quantities can be seen in all places along the road where it can lodge; this dirt becomes disagreeably apparent when standing on the car platforms. The stronger the blast, the more this effect. Spark-throwing is also prevalent to quite an extent in heavy business hours. The soft blast on the compound does away with much of the waste mentioned, and throws practically no sparks on the hardest service. Continued observations on car platforms were conclusive as to the cleanliness of this engine in regard to dirt through the stack. As an illustration of the softness of the blast, it may be remarked that there was nothing in the smoke box of the nature of deflecting plates or netting, a clear passage being left from the tubes to the atmosphere. For details and summary of comparative coal consumption, see Table 2.

WATER CONSUMPTION.

The water was measured as follows: A barrel was measured as to capacity, and then placed in position so that it could be filled and emptied into the tank readily until the tank was full, the height of water in the tank being taken after each barrel full. Each barrel full made an equal rise of water in the tank, showing the regularity of the tank capacity in height. The various readings of water consumed were made by means of a large float, to the centre of which was attached a graduated stick. The difference in any two readings on this stick when compared with top of man-hole, gave the amount of water used for that time in inches. The readings were made at about the point of the centre of gravity of the plan of the tank, and always at the same place on a level track. The first reading was made in the morning at the time the first weighed coal was used, with the water in the boiler just showing in the third gauge. When the yard was reached at night, the water was gauged with the same amount in the boiler, and the same pressure of steam as at the start. During the day the water was measured each round trip at Fulton Ferry, where water and coal were taken, the water being kept at the same point in the boiler at each time of measuring. After leaving the yard in the morning, the water in the boiler of the compound engine was allowed to fall to the second gauge, and was kept there through the day to insure dry steam. On the simple engine the water was kept at three gauges through the day. The overflow from the injectors on each engine flowed into a receptacle and was measured. Each reading on the gauge stick was checked by the engineer or fireman. For details and summary of comparative water consumption, see Table 2.

CYLINDER PERFORMANCE.

Indicator diagrams illustrating the cylinder performance under the varying conditions are attached. They are taken from a series of cards made on a surface road just before the engine was placed on the elevated structure, and are each typical of its class. They were made during a run

of twenty-seven miles between Providence and Kingston on the New York, Providence and Boston Railroad, with a miscellaneous freight train.

A three-fourths-inch pipe, eleven inches long, from each end of each cylinder, was connected to the indicator by a three-way cock in such a manner as to avoid abrupt turns, or small apertures; these connections were well wrapped with asbestos.

The cross-head motion was reduced by a special device of the pantograph type, calling for a string connection of but a few inches in length.

The pistons of the indicator were carefully watched and lubricated, and no signs of sticking are visible on the cards. The cards were all taken with a No. 80 spring.

The speed was taken with a revolution counter of positive action in the cab, the motion being taken from the pantograph. The steam gauge and indicator springs were tested before the cards were taken.

The valve motion is the ordinary Stephenson link as applied to locomotives generally, except the direction of its motion is reversed, the eccentrics being on the forward axle pointing toward the rear or main axle, with short eccentric rods. This was a feature that had to be contended against in endeavoring to get equal cut-offs and openings for the valves in all the various positions. For valve dimensions, etc., see Table 1.

The operation of taking a set of cards was as follows: There was a man at each indicator and a man in the cab. The latter at a desired time gave the indicator men a signal to be ready, and threw in the catch to the counter; he then gave a signal on the whistle at which the cards were taken simultaneously from each cylinder. The steam gauge and notch were noted, and at the end of ten seconds the speed counter was detached, and a reading taken. The speed was thus taken while cards were made, and cards were as near simultaneous as possible.

Steam chest lines were not taken on this day, it being desirable to use the shortest possible time in taking cards, and a previous trial having shown steam chest lines satisfactory. Cards showing these are shown on *Plates I, II* and *XXIX*.

Plates I to *XX*, inclusive, have each a set of high- and low-pressure cards, traced with the atmospheric line in common; and also a combined diagram showing the continuous expansion associated with hyperbolic expansion (full smooth curve), and with the expansion of dry saturated steam (dotted smooth curve). In the combined diagram, the front and back end cards are represented by full and dotted lines. Cards shown on *Plates XXI* and *XXII* were taken with the engine working upon the simple system. The speed at which cards 25 and 42 were taken is far in excess of what would be required, the simple system being desirable only in starting heavy trains, or running them under exceptionally hard conditions at slow speed. In these cards the admission line to the large cylinder shows the operation of the reducing valve to limit the initial pressure to a proper proportional amount, but the boiler pressure admission pipe to the large cylinder not being large enough to satisfy these

speeds, the steam was wire-drawn, which gives the difference in M. E. P. between the two cylinders, as figured on the cards. The contour of the cards from the large cylinder, however, shows the proper reduction of initial pressure which the reducing valve secures at a considerable piston speed, which was the object of taking the cards at the given speeds. *Plates XXIII* and *XXVII*, inclusive, show cards made with the engine starting from rest; of these *Plates XXVI* and *XXVII* simply show the action of the reducing valve in keeping the total admission pressure on each piston alike and constant while it is acting. *Plates XXIII* and *XXV*, inclusive, show the above action and also the time of the automatic action in changing to the compound system, showing the difference in pressure in the receiver at the time of the change and a revolution later.

Plate XXVIII has cards illustrating revolutions made by an ordinary compound engine after the throttle is shut, before the passages are freed from pressure, when the reverse lever is in the last notch. In yard work this is a hindrance, and is undesirable at any time, when it is necessary to stop before the engine can clear itself of steam. This can be obviated by the use of the device which allows this engine to be used as a simple engine.

Table 3 contains results from thirty-eight cards, tabulated for easy reference. This table includes the steam weight accounted for by the diagrams; and is arranged consecutively in order of the different notches and speeds. The cards are from the same lot from which those illustrated were taken, and includes them. This table offers an opportunity to compare the difference in cylinder economy between high- and low-pressure steam under similar conditions. It also shows the water consumption to vary but little through the varying speeds under like pressures of steam at the same cut-offs.

It is believed that the table and cards embody good general results, and show to good advantage in comparison with those from ordinary locomotive practice. The loss in pressure by the passage through the receiver is small for both slow and fast revolutions. The admission line is good, and the expansion lines of the different diagrams hold closely to the curve of saturated dry steam, tending to show a small amount of initial condensation. The water per horse-power per hour, which is the test of economy, figures low even on the cards doing work at fast speeds.

This low water rate for work done, shown by cards, is verified by the result of the actual service test, in which nearly twenty-four per cent. less water was used by the compound than by the simple engine in doing practically the same work for fourteen hours. The work done by each cylinder is practically alike at the third and fourth notches, and varies by degrees in opposite ways from that point, as shown by Table 3. The design was to have the point of equal power near the point of average work. This engine with light trains works in the first and second notches, and with heavy trains in the third and fourth notches, always starting from the seventh or last notch.

The low exhaust pressure shown on all cards, at the ordinary working

notches, is one cause of the water economy, and also signifies the style of action on the fire, these light exhausts occurring but twice a revolution in place of four times.

STRESS EFFECTS.

Aside from the economy in fuel and water consumption, an important result of the difference in cylinder performance between a simple and compound locomotive, under similar conditions, is that the latter should bring to bear upon the moving parts a more continuous or even stress, while subjecting those parts to loads of less magnitude at the point of maximum stress. The effect of the applied power should also be more regular in the compound engine. As illustrative of this effect, graphically, diagrams on *Plates XXX* to *XXXIII*, inclusive, give the rotative effect on each crank pin, together with the resultant effect for one revolution. The data taken for a simple locomotive, in working up these diagrams, are actual cards selected from first-class locomotives having Richardson-Allen valves, and a good steam distribution. Those for a compound are taken from No. 58, with initial pressures and M. E. P.s' to match the cards from the simple engine. These plates explain themselves, and suggest a steadier moving engine, more especially at high speeds, and the shortest cut-offs.

Plates XXXIV and *XXXV* show diagrams made from the same data, illustrating graphically the stress upon the crank pins, and hence the other moving parts, for one revolution. It will be observed that the lines representing the stresses on the compound crank pins keep within closer vertical limits than those on the simple engine, also, that the former keeps much nearer a continuous line, sudden variations in load being inappreciable.

GENERAL SUMMARY.

A reference to Table 2 shows the decided saving in water and fuel consumption, under the conditions of a fourteen hours' test heretofore described; this would be anticipated from diagram results in Table 3. Aside from the first cost and labor of handling this saving affects the time lost by the engines in coaling and taking water. The latter is of evident value on limited trains. In the elevated service it enables, in many cases, an engine which reaches the terminal late to save the time that would otherwise be used in taking water, thereby preventing the following train from being held by a signal. This was a fact noticed and commented upon by the train despatcher at the terminal where water and coal were taken.

The capabilities of the compound to equal the simple engines, in making short runs, on quick time, were fully demonstrated. This compound, by reason of its ability to be run at will as a simple engine, can equal the maximum power of a simple engine, when the small cylinder on the compound equals in size each of those on the simple, and the steam pressures are alike.

The smoothness of running on the compound, as compared with the simple, is noticeable in riding on the engines. This is explained by a com-

parison of the resultant rotative effects on the crank pins for the different systems, as illustrated graphically, with data, in *Plates XXX* to *XXXIII*, inclusive. This is a very desirable result as it affects the connections through the whole train.

The crank pins and reciprocating parts are not subject to such high pressures or sudden variations in stress during each half stroke in the compound, a result greatly to be desired. A comparison of stresses on the two systems, with data, is graphically illustrated in *Plates XXXIV* and *XXXV*.

Cylinder oil can be used with the best economy in the compound engine, the oil fed to one cylinder passing through both.

The cleanliness of the compound from cinders and sparks is a strong point in its favor. Its comparative stillness is also another desirable factor under certain conditions of service.

SECTION 2—FAST EXPRESS SERVICE.

Description of Engines.

The compound locomotive (No. 2600) was designed for making fast time on trains with few stops; and for a road with a level or rolling surface; the idea being to test its merits on this class of service against the ordinary type of express locomotives.

The engines used in competition with No. 2600 were No. 34, New York, Providence and Boston Railroad, and engines Nos. 136 and 173, Boston and Albany Railroad; the latter two being similar engines. The main dimensions of all three are found in Table 4 following. An inspection of these tables will show that the engines were very similar, the compound having very little advantage in heating surface, and a disadvantage in tractive power which counted against it on the heavy grades of the Boston and Albany Railroad, work for which this engine was not designed.

The action of the compound engine in starting and changing automatically to the compound system, and also the ability to run as a simple engine, are the same as described under Section 1.

Illustrations of the auxiliary and intercepting valve are shown in *Figs.* 1, 2 and 3.

SERVICE.

No. 2600 has been in successful general service on all the heavy and fast trains on the New York, Providence and Boston Railroad, between Providence and New London, a distance of sixty-four miles. The terminals are at tide water, and the intervening road has a rolling surface, there being grades each way from one-half to one per cent. The line of road is practically straight. Tables 5 and 6 give the results of competitive trials on two of these trains; that represented by Table 5 was made to show coal economy only.

The service on the Boston and Albany Railroad was between Boston and Springfield, a distance of ninety-nine miles, and was of a different nature from that on the New York, Providence and Boston Railroad, This will be seen on reference to the profile sketch following, the steepest

grades on this road having bad curves. In making the schedule time between the terminals, advantage cannot be taken of the down grades to the extent of over forty-two miles per hour; and the making up of lost time is limited to five minutes each between Worcester and Springfield and Worcester and Boston; thus the time which an engine designed for a more level road might lose on a bad up-grade could not be made up on the down-grades, and but five minutes could be made up on the levels. In order to make the running time, therefore, little time can be lost on the hills. The compound, as before-mentioned, is not designed for this class of service, but, as will be seen on reference to Tables 7 and 8 following, it had no difficulty in making its time with the other engines. Its ability as a hill climber was fully recognized after its experience with these trains. This was due to its excellent staying qualities when worked to full capacity as a compound, together with its ability to get under way quickly from a bad starting place as a simple engine.

CONDITIONS OF TEST.

The competing engines on each trial were run on the same trains, the same number of days, with the conditions as nearly alike as possible, the same engineer handling each engine, enough days being taken to insure a fair average. The engineers had no experience with the compound previous to the first day of each test; but were regular runners on the competing simple engine, with the following exception: On the trial of March 16th to 21st, inclusive, the engineer had No. 34 but a few days before the test. The runs on the Boston and Albany Railroad were exceptionally hard for each engine, as the road was undergoing repairs in numerous places between Boston and Springfield, which necessitated many slow-ups and extra stops.

On the New York, Providence and Boston Railroad, the conditions were very similar for each engine on each trial, with the exception of the runs on March 20th and 21st, recorded in Table 5. On these dates the train, being an hour late from New London, was obliged to make extra station stops, besides stopping for several signals, and slowing up for the suburban trains at stations near Providence. This affected the elapsed time between New London and Providence and also the general average of running time.

COAL AND WATER CONSUMPTION.

The coal economy, as given in Tables 5 to 8, inclusive, is based on car mileage. The results are practically the same when based on ton mileage. Coal was weighed to the engine at the beginning of each trial, there being a low fire and no coal on the tank; that used by each engine includes the banking for over night. At the finish of the last run of a series, the fire was allowed to burn low, and the remaining coal in the tank was weighed back. The coal account, in all cases, was kept by an employé of the railroad company.

The quality of coal on the New York, Providence and Boston Railroad was ordinary bituminous, about one half lumps.

The coal used on the Boston and Albany Railroad was best quality of Pocahontas, well mixed with lumps.

Accurate water measurements were attempted on but one test, objections being made to the delay incident to taking accurate readings when water is taken on the line of the road. From the observations which were made, however, there is every reason to believe that the trial in which the water was measured was the one in which least was saved. This would follow from the fact that it was the lightest of the four tests in point of work done, and that in which the least coal was saved.

On the test in which water was measured, careful attention was paid to the measuring of all quantities not used in the cylinder, and high water in the boiler was guarded against. The water in the boiler water-glass, was at the same place when final tank reading was taken at the end of the round trip, as when the first reading was made, the engine standing at the same spot.

CYLINDER PERFORMANCE.

Indicator diagrams were taken from No. 2600, in Section 1; and the diagrams shown in *Plates I* to *XXIX*, inclusive, fairly represent those taken from No. 2600 under the same general conditions, the ratios of cylinder areas being the same in each case. The cylinder powers show very nearly equal.

Plate XXI shows diagrams taken for experimental purposes as explained in Section 1.

Plate XXII shows diagrams taken in the simple system, the conditions being the same as those under which it is designed to be used when run as a simple engine. No. 47, on this plate, was taken at an early cut-off to show the action at that point.

GENERAL SUMMARY.

A reference to Tables 5 to 8, inclusive, will show the saving in fuel consumption made by the compound, on each given service, running in competition with selected engines on the respective roads; the engineer in each case being the regular runner of the simple engine, but handling the compound for the first time. The engineers all claimed that they could do more justice to the compound on a longer acquaintance.

All the engines were as nearly alike as was possible under the circumstances, the cylinder action excepted; and the differences in heating surface alone were too small to affect appreciably the fuel consumption.

The compound has met satisfactorily all requirements of hard work and fast running that have been placed upon it.

In point of cleanliness, *i. e.*, freedom from cinders and black smoke, the compound is a marked contrast to the simple engines. This feature was quickly observed and remarked by the engineer and trainmen on the first trips on each new train. From this fact the question naturally arises why the compound could not be substituted for the large and heavy anthracite coal burners which are run at large expense and considerable trouble

on some fast trains simply on account of the item of cleanliness. No. 2600 needs and has no netting in the smoke-box.

If the compound locomotive can be run so that the smoke and cinder nuisance is satisfactorily dispensed with, which would seem to be the case, the cost of operating it as compared with an anthracite coal burner may be illustrated from an actual case as follows: Trains 23 and 42, New York, Providence and Boston Railroad (see Table 5) have an anthracite locomotive for a regular engine; it runs 29·5 miles per ton of coal as a regular average. Another anthracite locomotive on a somewhat lighter service on the same road runs 30·5 miles per ton. Comparing the cost of anthracite fuel on trains 23 and 42, with the cost of bituminous fuel used by the compound on same trains (forty-two miles per ton), the saving in cost is forty-eight per cent., the bituminous coal costing twenty-six per cent. less delivered than the anthracite.

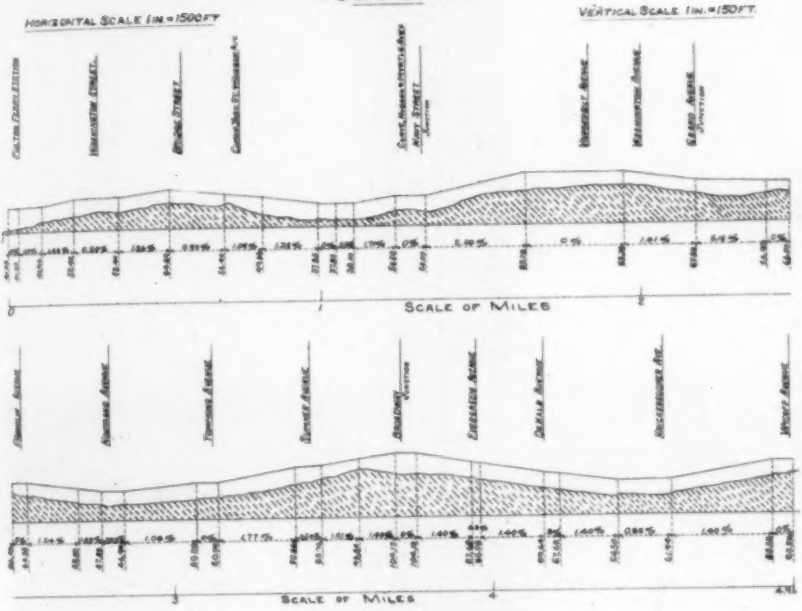
It is claimed that in a properly designed compound locomotive, the stress effects of the reciprocating and revolving parts should be more regular than in a simple engine, exerting the same power. (See Stress Effects, Section 1.) No. 2600 has never shown a suggestion of heating in any of the bearings or journals, all of which are of the ordinary size. The fastest and hardest work has called for but the most ordinary care in the lubrication of parts. The voluntary verdict of all the engineers is that it is an uncommonly cool running locomotive, light on oil, and easy to take care of; the latter in their estimation being quite a point in favor of the compound.

The ability of this type of compound to be run as a simple engine enables it to be run with either cylinder singly, in case of break-downs, with no more trouble than an ordinary engine.

No. 2600 has so satisfactorily met all requirements of heavy and fast express service that have been placed upon it for several consecutive months, that the builders believe themselves justified in claiming, as a conservative estimate, a saving of fifteen per cent. to twenty-five per cent. fuel on express service by a properly proportioned compound of this type, in competition with a simple locomotive, the amount of saving depending on the service; also a decided advantage in cleanliness; and freedom from heating tendencies, the latter signifying light oil consumption.

— PROFILE SKETCH —

RIDGEWOOD LINE
— OF THE —
UNION ELEVATED R.R.
FULTON FERRY STATION TO WYCOFF AVENUE
— BROOKLYN, N.Y. —



— PROFILE SKETCH —

BOSTON AND ALBANY R.R.
— BETWEEN —
SPRINGFIELD AND BOSTON

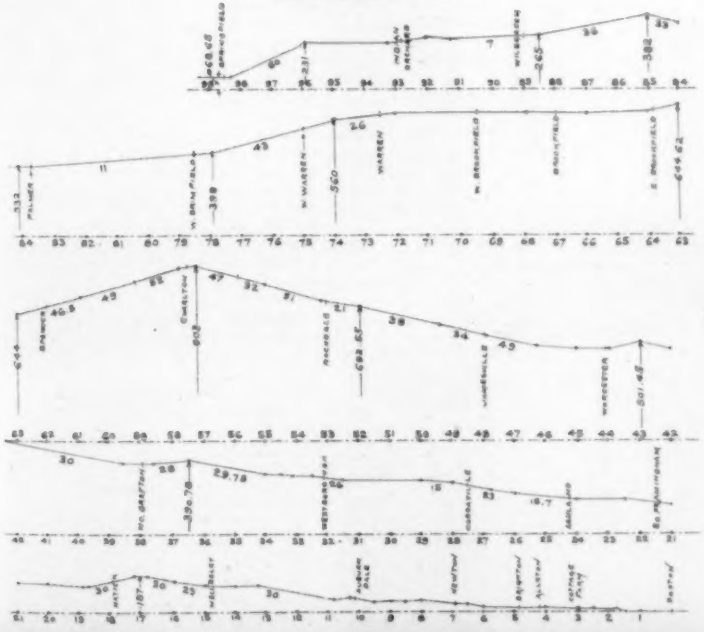


TABLE Nº. 1

LOCOMOTIVE DIMENSIONS.

TYPE	COMPOUND	SIMPLE.
FUEL	ANTHRA. COAL	ANTHRA. COAL
CYLINDER-SIZES-R.S.	18"×16"	11"×16"
" " -L.S.	11½"×16"	11"×16"
" -PORTS-STEAM-R.S.	1"×17"	⅞"×8⅝"
" " " -L.S.	⅞"×10"	⅞"×8⅝"
" " -EXHAUST-R.S.	2"×17"	1¾"×8⅝"
" " " -L.S.	2"×10"	1¾"×8⅝"
" -CLEARANCE-R.S.	10.2 %	8 %
" " " -L.S.	11 %	8 %
STEAM PIPE FROM BOILER-R.S.	2" DIA.	3" DIA.
" " " " -L.S.	3½" "	3" "
PISTON ROD DIAMETER	2"	2"
DRIVERS-DIAMETER	42"	42"
" -REVOLUTIONS PER MILE	480	480
BOILER-DIAMETER	42"	42"
" -FLUES-O.D.	1½"	1⅝"

TYPE	COMPOUND	SIMPLE
BOILER-FLUES-NUMBER	124	124
" " -LENGTH	65⅞"	68⅝"
EXHAUST TIP DIAMETER	3"	3¼"
GRATE-STYLE	WATER GRATE	WATER GRATE
" -SIZE	54¾"×41"	54¾"×41"
" -AREA	15.6 SQ. FT	15.6 SQ. FT
HEATING SURFACES-TOTAL	2894.6 "	2894.6 "
" " -FIREBOX	45.46 "	45.46 "
" " -FLUES	244 "	244 "
AREA RATIO-HEATING SURFACE TO GRATE	18.5	18.5
STEAM CHEST VALVE-STYLE	BALANCED	BALANCED
" " " -FULL TRAVEL	5"	5"
" " " -LAP OUTSIDE	PP. ⅞" : P. 1"	⅞"
" " " -CLEARANCE	PP. ⅛" : P. [illegible]	1/32 LAP
WEIGHT-LOADED	45850 LBS.	45350 LBS.
" " -ON DRIVERS	31834 "	31034 "
" " -ON TRUCK	14016 "	14016 "

TABLE Nº 2

GENERAL DATA OF TESTS.

TIME		TRIPS	MILES	NO. OF CARS	CAR MILES	RUNNING TIME		COAL USED FOR		TON MILES PER LBS		WEATHER	CONDITION OF ENGINES		REMARKS
ENG.	ENG.	'82	'88	'82 '88	'82	'82	'88	'82	'88	'82	'88		'82	'88	
6.02	5.58					0.52		38		47					
6.00	6.05	1						1140	1445						
6.33	6.35	EXCURS.	6	4	24	35m	30m	1006		560	471				
7.07	7.08	1													
7.31	7.34	TO RIDGE	6	4	20	24m	26m								
7.55	7.59	2													STOP SIGNAL AT '88 TERMINAL FOR '82
8.00	8.06	TO F.F.	5	4	20	25m	26m			3062	1914				
8.14	8.10	3													
8.44	8.40	TO RIDGE	5	4	20	22½	28m								STOP SIGNAL AT '82 TERMINAL FOR '88
8.45	8.46	4													
9.06	9.11	TO F.F.	5	4	20	23m	28m			2842	1878				
9.19	9.21	5													
9.41	9.45	TO RIDGE	5	3	15	22m	24m								
9.51	9.56	6													
10.13	10.16	TO F.F.	5	2	10	22m	24m		500	2277	1787				
10.28	10.32	7													
10.47	10.44	TO RIDGE	5	2	10	23½	28½								
10.57	10.56	8													
11.21	11.22	TO F.F.	5	2	10	24½	26½			1811	1428				
11.38	11.38	9													
11.53	11.58	TO RIDGE	5	2	10	22½	23m								
12.08	12.06	10													
12.34	12.28	TO F.F.	5	2	10	24m	24m			1695	1296				
12.58	12.57	11													
12.58	1.01	TO RIDGE	5	2	10	24½	24m								
1.10	1.09	12													
1.34	1.28	TO F.F.	5	2	10	24m	25½	880		1818	1428				
1.43	1.40	13													
2.07	2.02	TO RIDGE	5	2	10	24m	24½								
2.19	2.14	14													
2.50	2.50	TO F.F.	5	2	10	23½	24m		500	1767	1502				
3.00	2.48	15													
3.13	3.16	TO RIDGE	5	2	10	23m	24m								
3.32	3.32	16													
3.46	3.48	TO F.F.	5	2	10	24m	23½	500		1870	1502				
3.55	3.56	17													
4.06	4.19	TO RIDGE	5	2	10	23½	24m								
4.27	4.28	18													
4.54	4.50	TO F.F.	5	3	15	26½	25m	500		2089	1690				
5.08	5.12	19													
5.30	5.36	TO RIDGE	5	4	20	25m	26m								
5.47	5.42	20													
6.01	6.05	TO F.F.	5	4	20	24m	23m	196		2812	1944				
6.23	6.12	21													
6.46	6.46	TO RIDGE	5	4	20	23m	24m								
7.00	6.53	22													
7.23	7.16	TO F.F.	5	3	15	23½	23m	66		2768	1899				
7.38	7.31	23													
7.58	7.50	TO C. NY.	6	4	24	26½	24m			721	1178				
TOTALS		24	122		360			3899	2430	84	70				

RESULTS

GAIN IN FUEL OVER '82. AV. FOR DAY- 27.7%	WATER EVAPORATED AT 0# PER POUND FUEL IN '82 AT 150 LBS PRESSURE = 6.69 LBS
AV. COAL PER CAR MILE FOR DAY '82 = 11.05 LBS	WATER EVAPORATED AT 38# PER POUND FUEL IN '88 AT 150 LBS PRESSURE = 8.26 "
" " " " " " '88 = 6.80 LBS	AV. WATER PER CAR MILE FOR DAY '82 = 7088 LBS
GAIN IN WATER OVER '82 AV. FOR DAY - 23.8%	" " " " " " '88 = 5627 "
" " " " " 344 CAR TRIPS 26%	" " " " " 344 CAR TRIPS '82 65.04%
" " " " " 2 " " 20%	" " " " " 2 " '88 48.11%
EQUIVALENT AT 0# OF WATER EVAPORATED IN '88 AT 47.2 0.069	'82 85.09%
EQUIVALENT EVAPORATION FROM & AT 212° - '82 = 8.09	'88 71.14%
" " " " " " '88 = 9.97	

TABLE No 3.

INDICATOR CARD RESULTS.

Card No.	Initial Pressure	Revs Per Minute	Notch And Cut-Off	Horse Powers (H.P) H.P	H.P	H.P. Ratio E to H.P.	Water Per H.P Per Hour Accounts to be By Indicator - In Pounds. H.P Cut-Off	H.P Release	E Cut-Off	E Release	Remarks.
11	196	192		83.45	68.69	.130	14.97	16.07	15.46	16.78	Experimental
10	196	258		96.75	79.35	.119	16.19	16.99	15.49	16.29	Cards
47	135	246		72.43	90.18	.124	17.25	17.77	16.81	18.24	
46	133	246		76.56	89.37	.117	15.46	16.61	16.13	17.65	
7	115	270		65.62	74.21	.117	19.82	19.66	17.68	19.98	
51	140	270		84.57	106.8	.126	17.85	19.00	15.91	17.10	
50	143	282		81.41	103.4	.127	18.96	19.02	16.39	18.37	
8	138	294		88.85	100.9	.101	19.48	19.24	18.46	18.44	
45	128	300		70.38	93.49	.133	19.91	19.86	19.25	19.89	
46	141	324		91.55	116.6	.127	18.98	18.95	17.96	18.22	
25	117	120		76.87	81.21	0.89	—	—	—	—	Simple
6	119	228		78.07	94.93	.122	19.82	19.22	18.20	18.81	
37	131	258		94.90	113.6	.120	19.09	19.15	18.04	17.86	
35	142	258		98.38	116.1	.122	19.78	20.25	18.39	18.88	
82	144	276		110.7	131.7	.119	18.82	18.50	17.64	18.40	
9	141	282		106.9	125.6	.117	19.29	19.42	17.82	18.67	
4	119	300		93.51	114.1	.122	20.51	20.26	19.89	20.28	
10	121	318		107.9	134.1	.124	19.61	19.48	18.62	20.18	
85	136	330		116.6	139.9	.120	19.82	19.56	18.57	17.96	
19	149	150		107.1	109.2	1.02	19.51	19.45	17.71	18.08	
20	147	234		125.6	133.0	1.05	19.86	20.00	18.87	18.69	
11	138	276		127.1	142.1	1.12	21.08	21.06	19.94	20.99	
34	134	282		125.9	148.5	1.18	20.46	20.14	19.70	19.65	
12	130	306		127.6	140.5	1.10	21.96	22.04	19.40	20.79	
42	127	150		119.2	93.74	0.79	—	—	—	—	Simple
15	124	210		107.6	108.1	1.006	22.27	22.10	19.88	21.56	
43	120	228		108.5	116.8	1.07	22.23	21.96	21.19	21.96	
44	129	252		130.1	133.7	1.03	20.70	20.02	21.45	21.61	
21	141	270		149.6	152.7	1.02	22.51	22.44	21.28	21.86	
31	134	168		104.4	118.0	1.13	20.86	20.79	20.91	20.80	
22	145	210		138.2	137.8	0.997	22.21	22.09	21.42	21.22	
23	128	264		143.9	142.5	0.99	24.40	24.38	24.57	20.97	
1	136	100		74.07	68.77	0.98	22.30	22.75	20.97	21.01	
17	143	192		134.0	132.6	0.99	22.87	22.78	22.53	23.29	
33	148	222		151.09	155.8	1.03	22.30	23.47	23.16	22.60	
32	144	270		178.0	165.6	0.95	25.66	25.98	25.29	25.12	
27	136	180		122.0	114.1	0.96	24.48	24.58	24.22	24.47	
28	134	216		135.6	132.9	0.99	26.75	26.43	26.05	25.79	

No. 11.

U.E. R.R. ENG. No. 58. PLATE I.

Steam 163½ Rev. 192

Scale 80.

AV. M.E.P. { HP 33.16 / E 17.40 Ref. to HP 42.63

TOTAL H.P. 122.12

R. I. Loco. W'ks % '90.

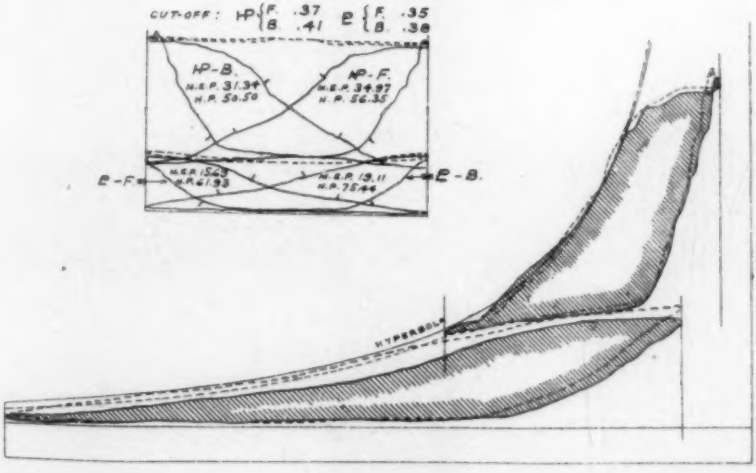


PLATE II.

No. 10.

U.E. R.R. ENG. No. 58.

Steam 163# Rev. 258

Scale 80.

Av. M.E.P. { HP 30.84 / P 14.95 } Ref. to HP 36.63

TOTAL H.P. 146.11

R.I. Loco. W'ks. ⅞ '90.

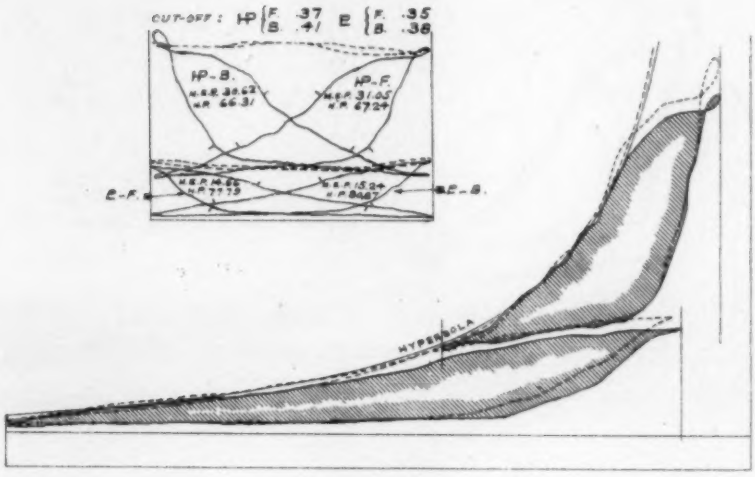


PLATE III

No. 47.

U.E.R.R. ENG. No. 58.

Steam 131#. Rev. 246.

Notch 1. Scale 80.

Av. M.E.P. { HP 35.09. / P 17.83. } Ref. to HP 43.68.

TOTAL H.P. 162.63

R.I. Loco. W'ks. 9/30 '90.

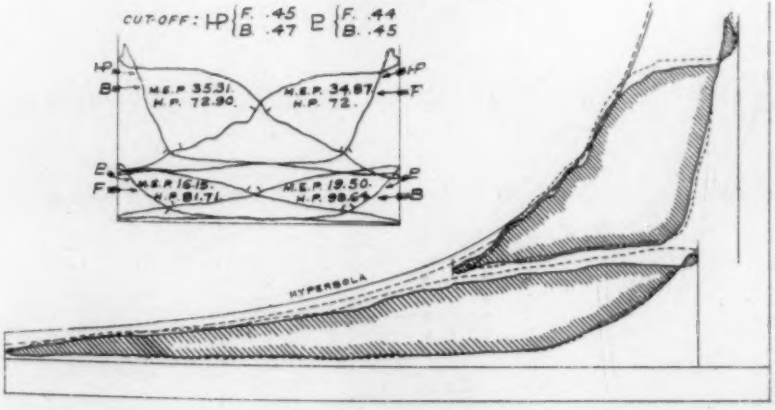


PLATE IV

No. 51.

U.E.R.R. ENG. No. 58.

Steam 159. Rev. 270.

Notch 1. Scale 80.

Av. M.E.P. { HP 36.82 / P 19.15 – Ref. to HP 46.92.

TOTAL H.P. 190.9

R.I. Loco. W'ks. 9/30 '90.

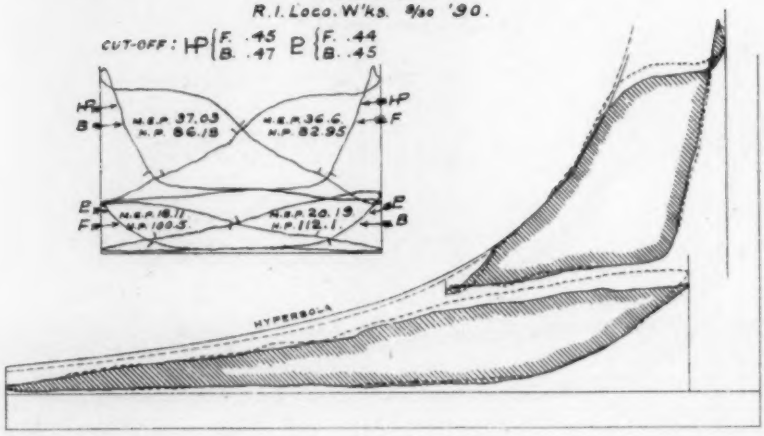


PLATE V

No. 46.

U.E.R.R. ENG. No. 58.

Steam 155. Rev. 324.

Notch 1. Scale 80.

Av. M.E.P. { HP 33.66 / P 17.46 Ref. to HP 42.78.

TOTAL H.P. 208.1

R.I. Loco. W'ks. 9/30 '90.

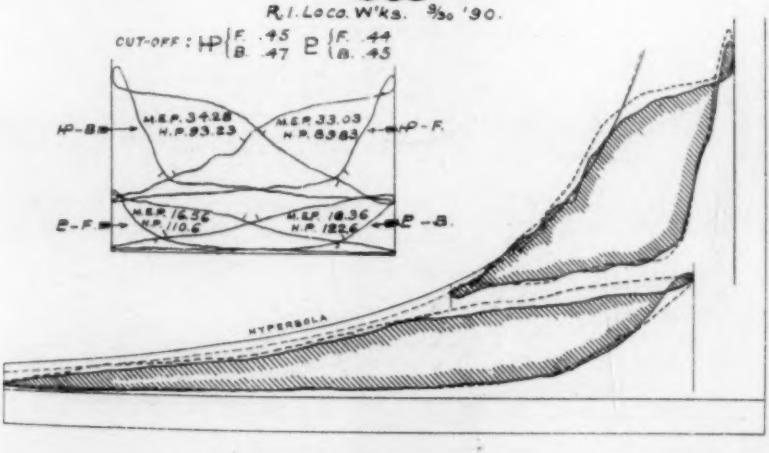


PLATE VI

No. 3.

U.E.R.R. ENG. No. 58.

Steam 139½ Rev. 228.

Notch 2. Scale 80.

Av. M.E.P. { HP 40.80 / P 20.25 } REF. to HP 49.61

TOTAL H.P. 173.

R.I. Loco. W'ks. 5/30 '90.

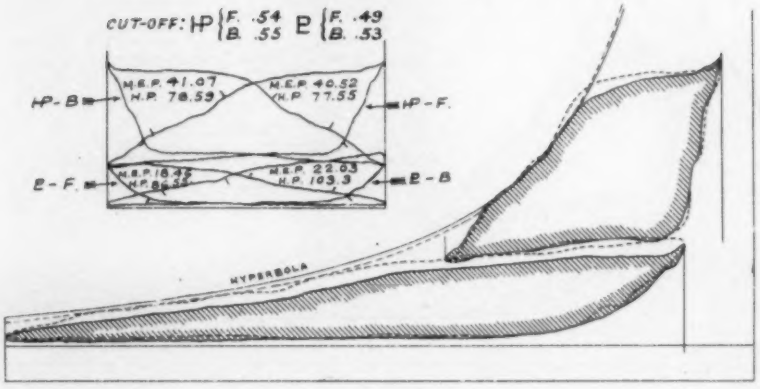


PLATE VII

No. 52.

U.E.R.R. ENG. No. 58.

Steam 161. Rev. 276.

Notch 2. Scale 80.

Av. M.E.P. { HP 47.78 / P 23.21. } REF. to HP 56.86.

TOTAL H.P. 242.4

R.I. Loco. W'ks. 5/30 '90.

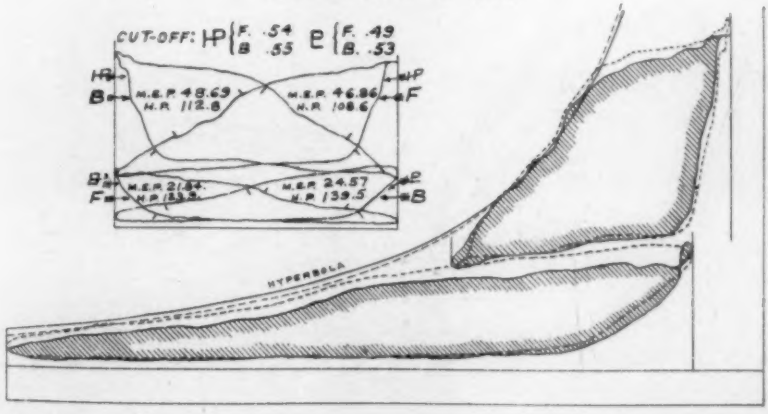


PLATE VIII

No. 35.

U.E.R.R. ENG. No. 58.

Steam 157. Rev. 330.

Notch 2. Scale 80.

Av. M.E.P. { HP 42.07 / P 20.61 } REF. TO HP 50.49.

TOTAL H.P. 256.5.

R.I. Loco. W'ks. 3/30 '90.

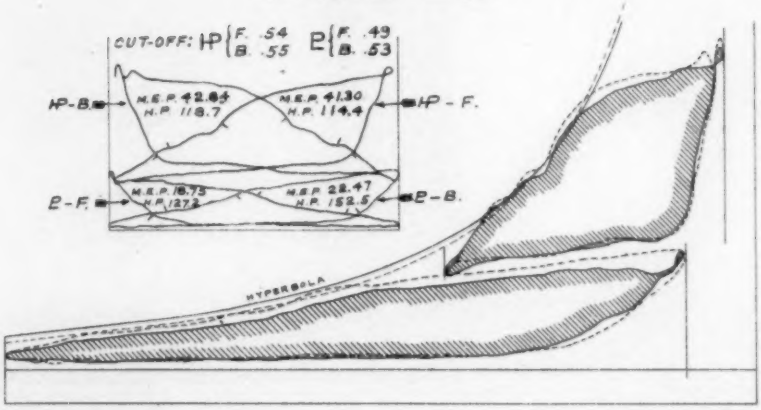


PLATE IX

No. 19.

U.E.R.R. ENG. No. 58.

Steam 161 Rev. 180

Notch 3. Scale 80.

Av. M.E.P. { HP 70.87 / P 29.49 } REF. TO HP 72.25

TOTAL H.P. 216.3

R.I. Loco. W'ks. 3/30 '90.

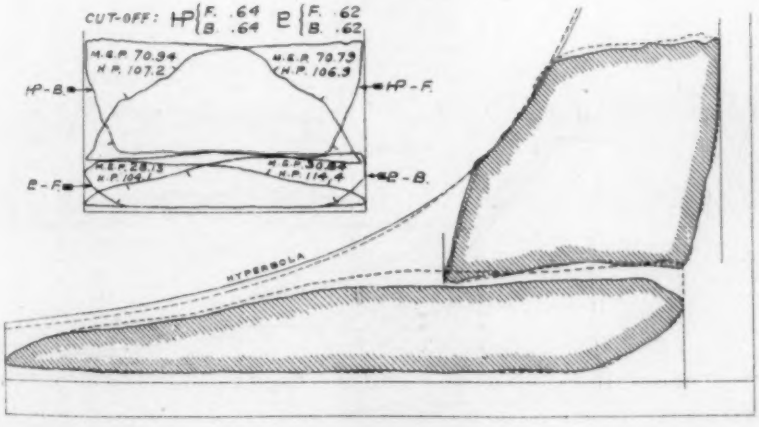


PLATE X

No. 34.

U.E.R.R. ENG. No. 58.

Steam 148 Rev. 282

Notch 3. Scale 80.

Av. M.E.P. { HP 53.20 / P 25.60 } REF TO HP 62.72

TOTAL H.P. 274.4

R.I. Loco. W'KS. 3/30 '90.

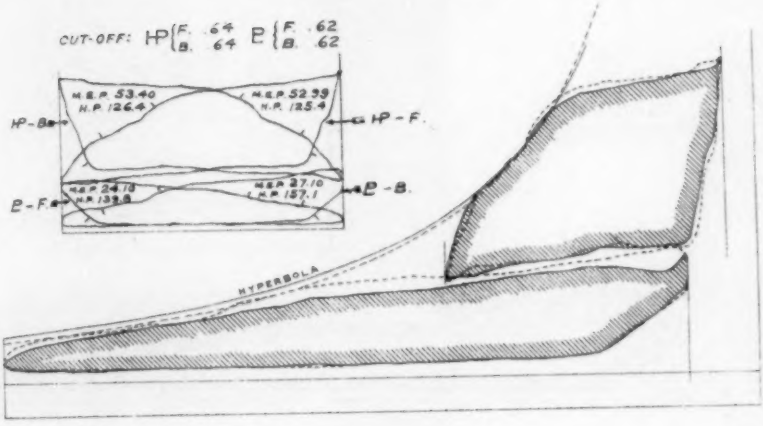


PLATE XI

No. 12.

U.E.R.R. ENG. No. 58.

Steam 148½ Rev. 306

Notch 3. Scale 80.

Av. M.E.P. { HP 49.70 / P 22.33 } REF TO HP 54.71

TOTAL H.P. 268.1

R.I. Loco. W'KS. 3/30 '90.

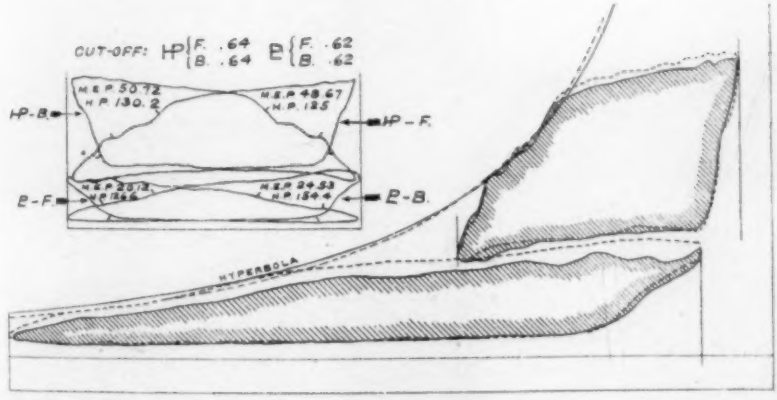


PLATE XII

No. 15.

U.E.R.R. ENG. No. 58.

Steam 135½ Rev. 210

Notch 4 Scale 80

Av. M.E.P. { HP 61.01 / P 25.06 } REF. to HP 61.40

TOTAL H.P. 215.7

R.I. Loco. W'ks. 3/30 '90.

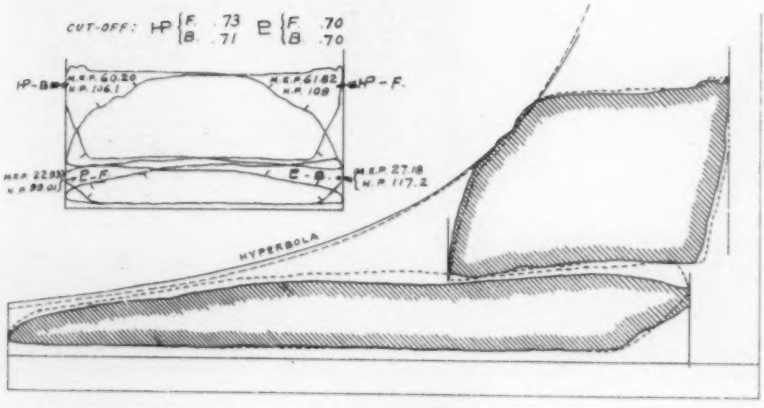


PLATE XIII

No. 44.

U.E.R.R. ENG. No. 58.

Steam 142½ Rev. 252.

Notch 4. Scale 80.

Av. M.E.P. { HP 61.51 / P 25.82 } REF. to HP 63.26

TOTAL H.P. 263.8

R.I. Loco. W'ks. 3/30 '90.

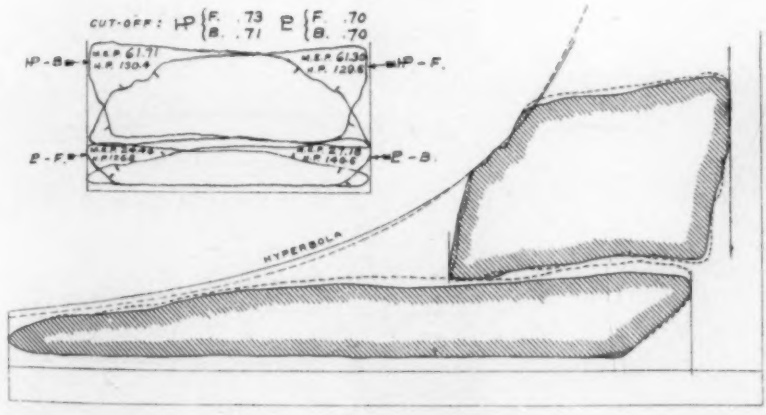


PLATE XIV

No. 21.

U.E.R.R. ENG. No. 58.

Steam 139 Rev. 270

Notch 4. Scale 80.

Av. M.E.P. { HP 66.02 / P 27.50 } Ref. to HP 67.37.

TOTAL H.P. 302.3

R.I. Loco. W'ks. 3/30 '90.

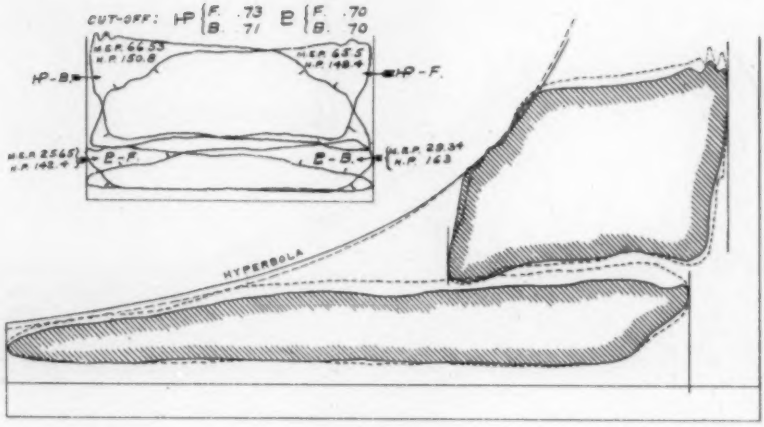


PLATE XV

No. 31.

U.E. R.R. ENG. No. 38.

Steam 145. Rev. 168.

Notch 5. Scale 80.

Av. M.E.P. { HP 74.01. / P 34.13. } Ref. to HP 83.64.

TOTAL H.P. 222.4.

R.I. Loco. W'ks. 3/30 '90.

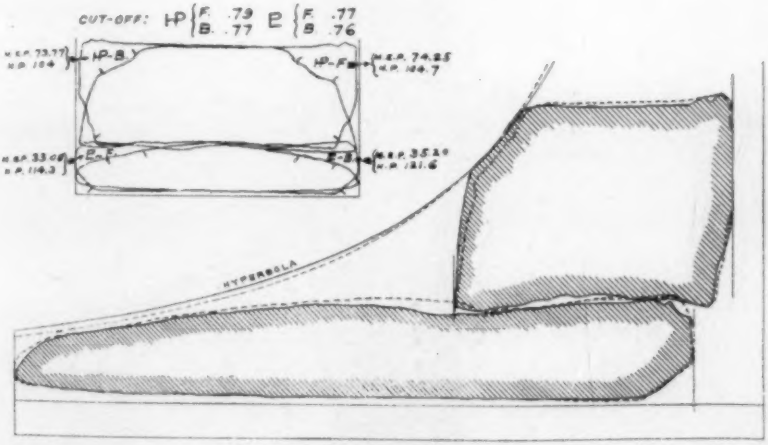


PLATE XVI

No. 22.

U.E. R.R. ENG. No. 58.

Steam 156. Rev. 210.

Notch 5. Scale 80.

Av. M.E.P. { HP 78.40. / P 31.92. Ref. to HP 78.20.

TOTAL H.P. 276.

R.I. Loco. W'ks. '90.

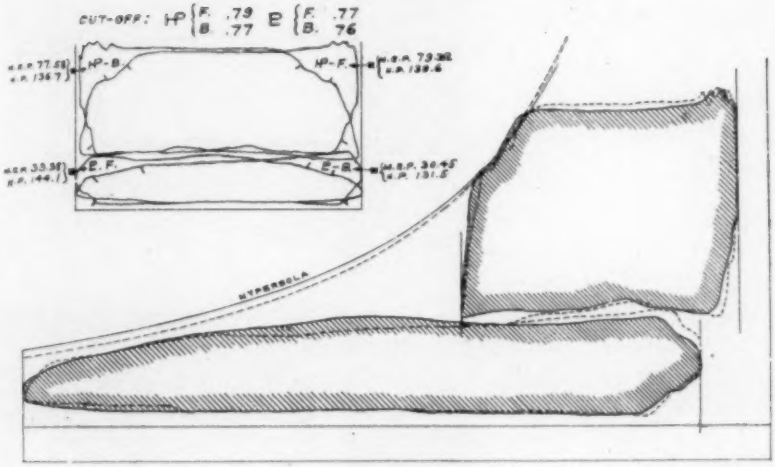


PLATE XVII

No. 1.

U.E. R.R. ENG. No. 58.

Steam 150. Rev. 100.

Notch 6. Scale 80.

Av. M.E.P. { HP 88.25 / P 33.45 Ref. to HP 81.95

TOTAL H.P. 142.84

R.I. Loco. W'ks. '90.

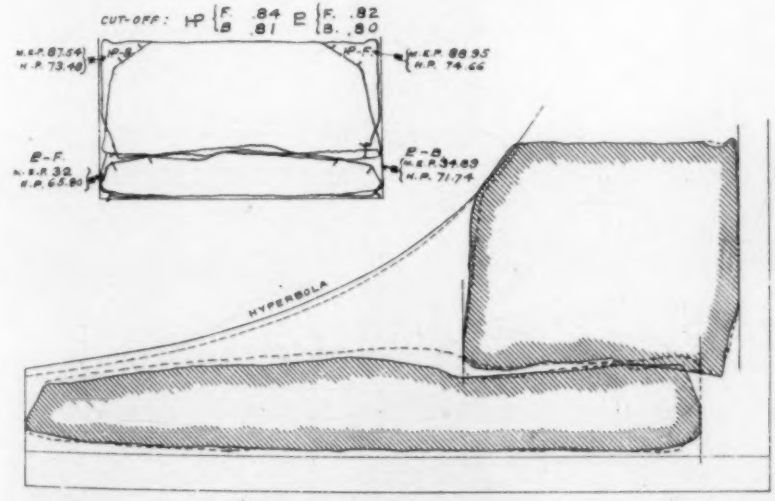


PLATE XVIII

No. 17.

U.E. R.R. ENG. No. 58.

Steam 156. Rev. 192.

Notch 6. Scale 80.

Av. M.E.P. { HP 84.15. / P 33.59. Ref to HP 82.30.

TOTAL H.P. 266.6

R.I. Loco. W'ks. ⅝₀ '90.

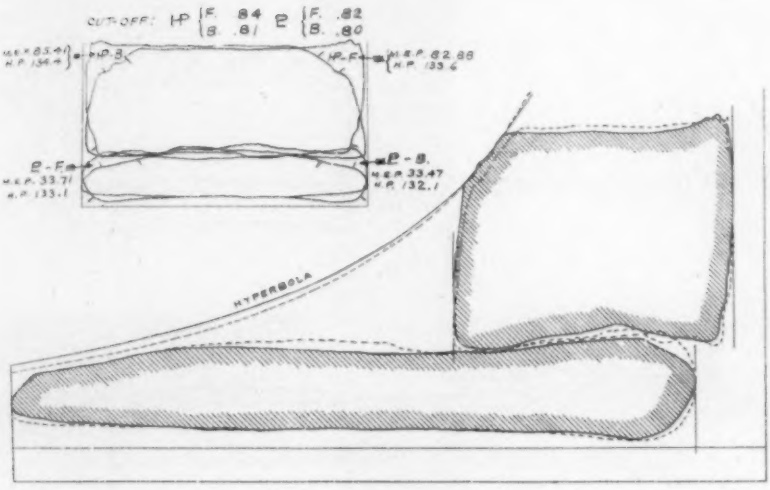


PLATE XIX

No. 32.

U.E. R.R. ENG. No. 58.

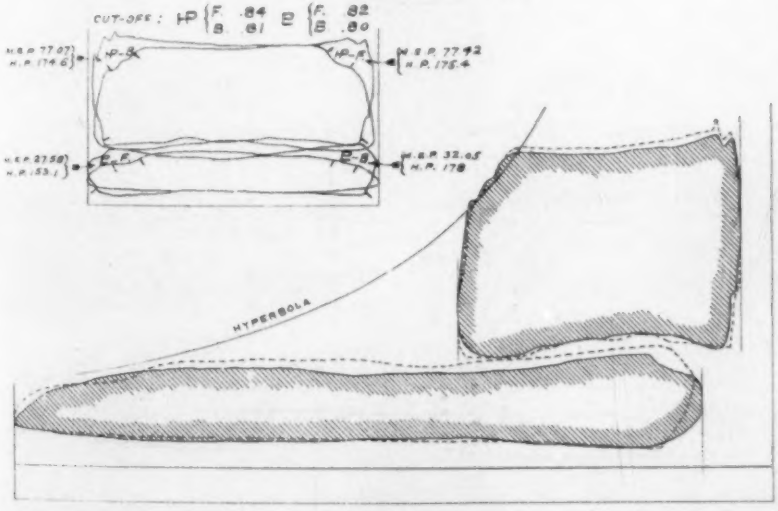
Steam 161. Rev. 270.

Notch 6. Scale 80.

Av. M.E.P. { HP 77.25 / P 29.82 Ref to HP 73.06

TOTAL H.P. 340.6

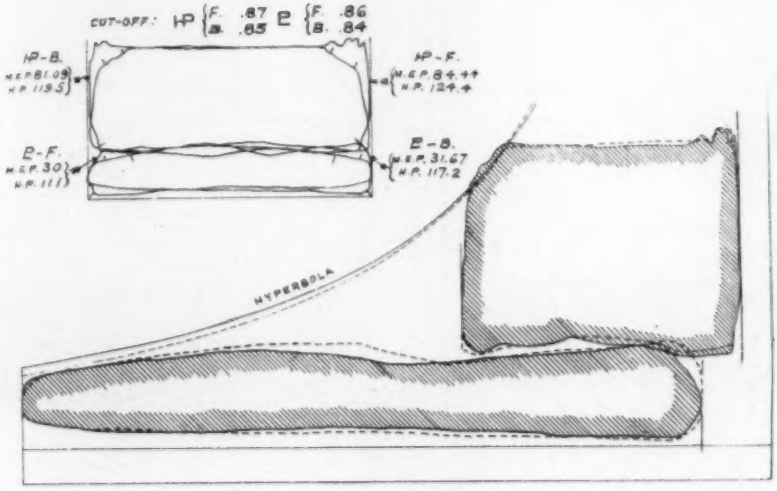
R.I. Loco. W'ks. ⅝₀ '90.



No. 27.

U.E. R.R. ENG. No. 58. PLATE XX

Steam 145. Rev. 180.
Notch 7. Scale 80.
Av. M.E.P. { HP 82.77 / P 30.84 } Ref. to HP 75.56.
TOTAL H.P. 236.1
R.I. Loco. W'ks. 9/10 '90.

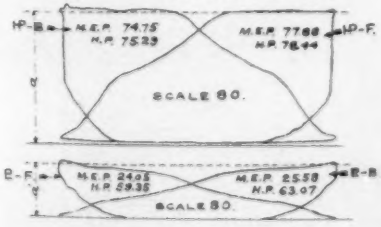


U. E. R.R. Eng. No. 58. PLATE XXI

DIAGRAMS IN SIMPLE SYSTEM.
R.I. Loco. Works.

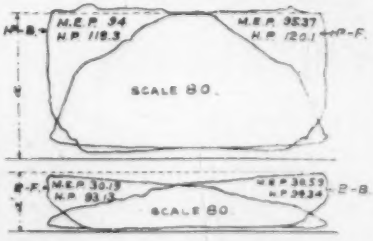
No. 25 9/10 '90
Speed 120 Rev.
Steam 128 Notch 1.
Av. M.E.P. { HP 76.31 / P 24.82 } Ref. to HP 60.81
TOTAL H.P. 188.08.

CUT-OFF: HP { F .45 / B .47 } P { F .44 / B .45 }



No. 42 9/10 '90
Speed 150 Rev.
Steam 139½ Notch 3.
Av. M.E.P. { HP 94.63 / P 30.39 } Ref. to HP 74.45
TOTAL H.P. 212.9.

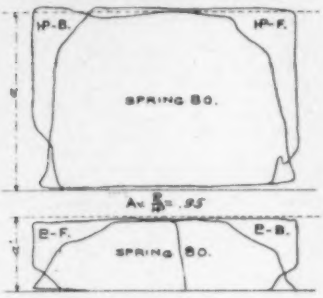
CUT-OFF: HP { F .64 / B .64 } P { F .62 / B .62 }



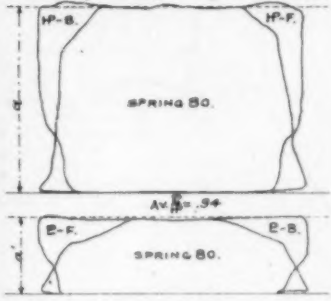
WHEN HP PISTON HAS PRESSURE @ THE P PISTON SHOULD HAVE PRESSURE @ TO MAKE EACH TOTAL PISTON PRESSURE EQUAL. THE P CARDS SHOW THE WIRE-DRAWING OF STEAM THROUGH THE REDUCING VALVE AT THESE SPEEDS.

ENG. No. 2600.
DIAGRAMS IN SIMPLE SYSTEM.
R. I. Loco. Works.

No. 1 ⅝ '91.
Speed Starting.
Av. M.E.P. { HP 136.87 / LP 83.38 } Ref. to HP 129.66.

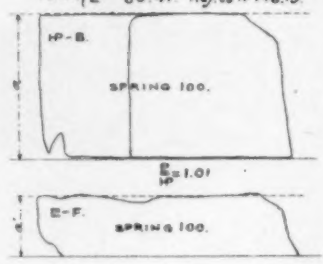


No. 23 ¾ '91.
Speed about 30 Rev.
Av. M.E.P. { HP 144.27 / LP 56.46. } Ref. to HP 136.63.

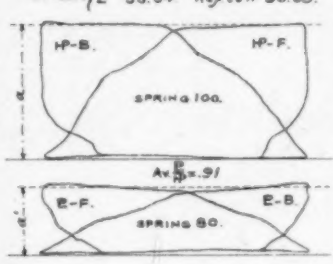


WHEN HP PISTON HAS PRESSURE a, THE LP PISTON SHOULD HAVE PRESSURE a' TO MAKE EACH TOTAL PISTON PRESSURE EQUAL. THE LP CARDS SHOW THE POSITIVE ACTION OF REDUCING VALVE.

No. 19. ⅝ '91.
Speed Starting.
M.E.P. { HP 144.39 / LP 60.41. } Ref. to HP 146.19.



No. 47 ⅞ '91.
Speed about 50 Rev.
Av. M.E.P. { HP 103.33. / LP 38.84 } Ref. to HP 93.39.



U.E.R.R. Eng. No. 58.
By
R.I. Loco. W'ks. ⅝ '90.

Engine starts from rest at z, (both cards), both cylinders using direct steam to y (LP card), one-half revolution.

a is initial pressure in HP cylinder. a' is initial pressure which LP cylinder should have, in order to make total pressures on both pistons equal.

X is the difference between pressure in receiver at time of changing into compound, and normal pressure in receiver when running compound, reverse lever remaining the same.

No. 20.
Steam 150. Notch 7. Scale 80.

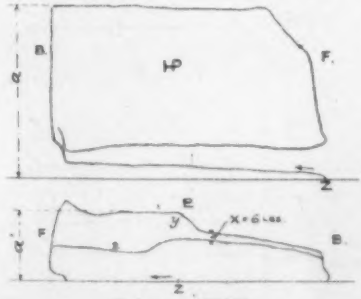


PLATE XXIII

No. 19.
Steam 148. Notch 7. Scale 80.

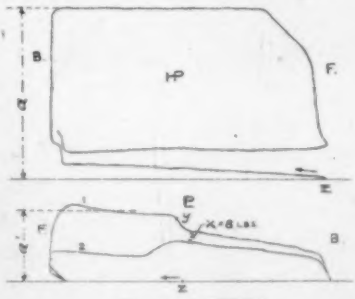


PLATE XXIV

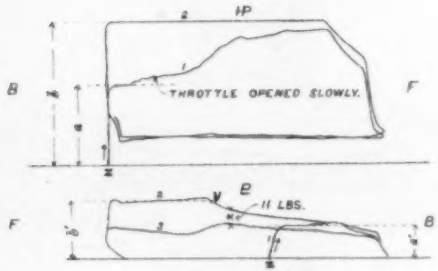
PLATE XXV

No. 14.
U.E.R.R. Eng. No. 58.
Steam 125. Notch 7. Scale 80.
R.I.Loco. W'ks. 5/8, '90.

Engine starts from rest at **z**, *(both cards), both cylinders using direct steam to* **y**, *(P card), nearly one revolution.*

a *is first initial pressure in HP cylinder.* **a'** *is first initial pressure which P should have, in order to make total pressures on both pistons equal.* **b** *is third initial pressure in HP cylinder.* **b'**, *(P card), is a pressure such that the ratio of* **b** *to* **b'** *is the same as the ratio of* **a** *to* **a'**.

x *is the difference between pressure in receiver at time of changing into compound and normal pressure in receiver when running compound, reverse lever remaining the same.*



U.E.R.R. Eng. No. 58.
By
R.I.Loco. W'ks. 5/8 '90.

Engine starts from rest at **z** *(both cards), both cylinders using direct steam, and changes into compound during exhaust stroke, (P card), not less than one-half revolution.*

a *is initial pressure in HP cylinder.* **a'** *is initial pressure which P cylinder should have in order to make total pressures on both pistons equal.*

No. 15.
Steam 118. Notch 7. Scale 80.

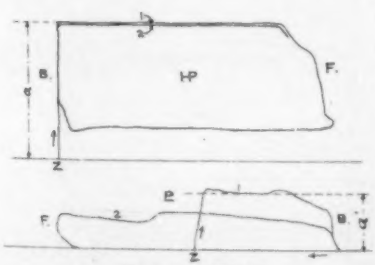


PLATE XXVI

No. 18.
Steam 145. Notch 7. Scale 80.

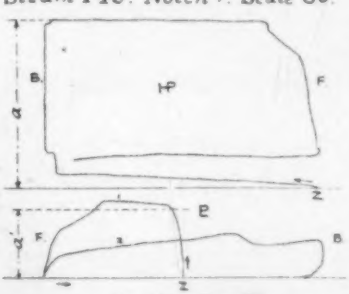
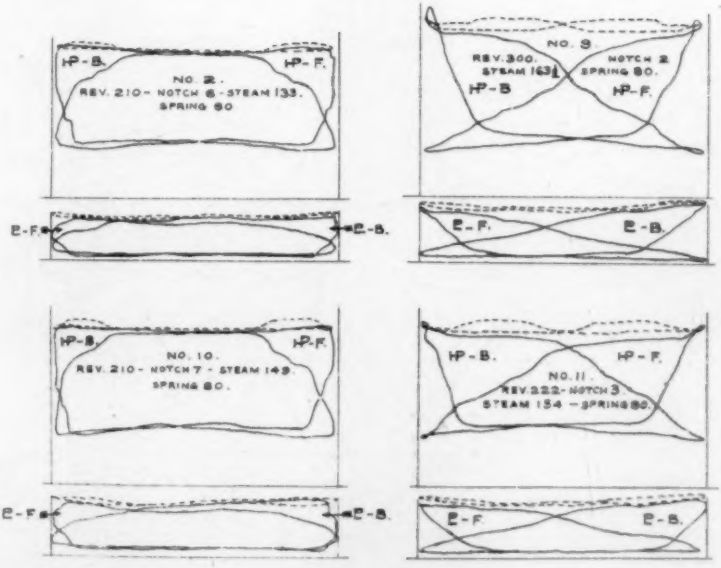


PLATE XXVII

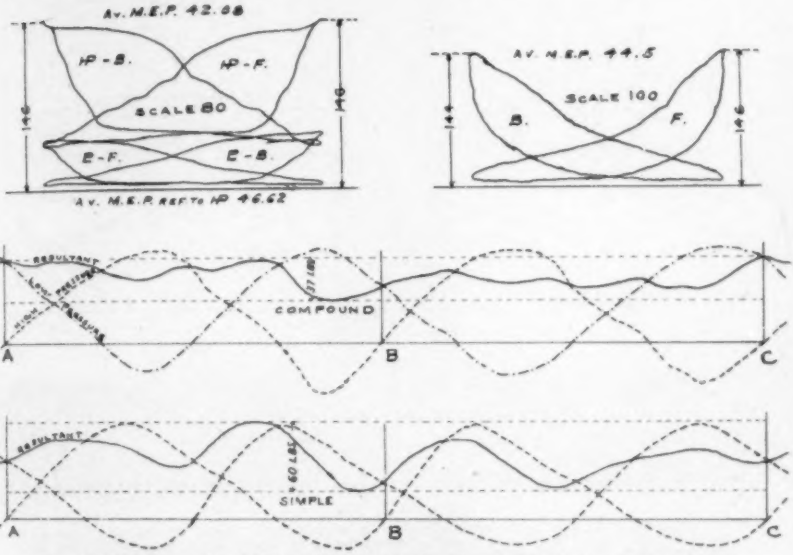
U. E. R.R. — Eng. No. 58. PLATE XXVIII

U. E. R.R. — Eng. No. 58. PLATE XXIX



ROTATIVE EFFECTS. PLATE XXX

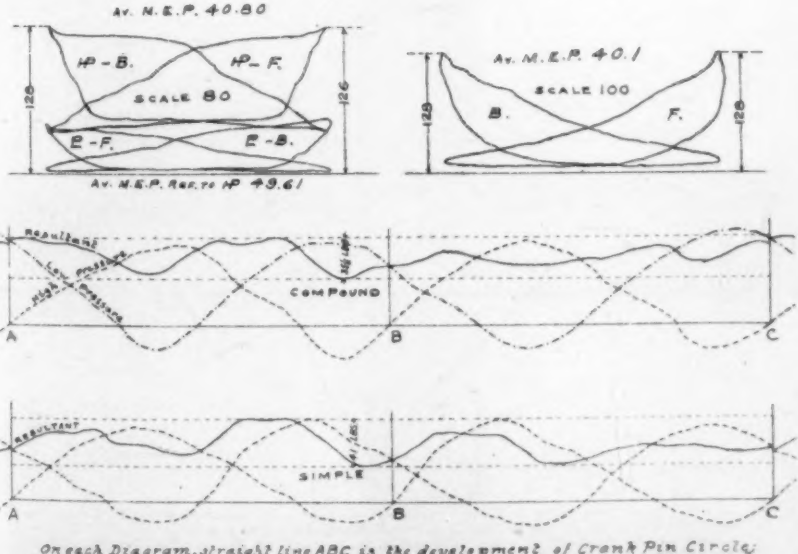
ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2" = 1 ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above ABC represent ROTATIVE EFFECTS, 1 in height equalling 80 lbs. per sq. in. of HP piston, exerted at Crank Pin at Right Angles to Crank.

ROTATIVE EFFECTS PLATE XXXI

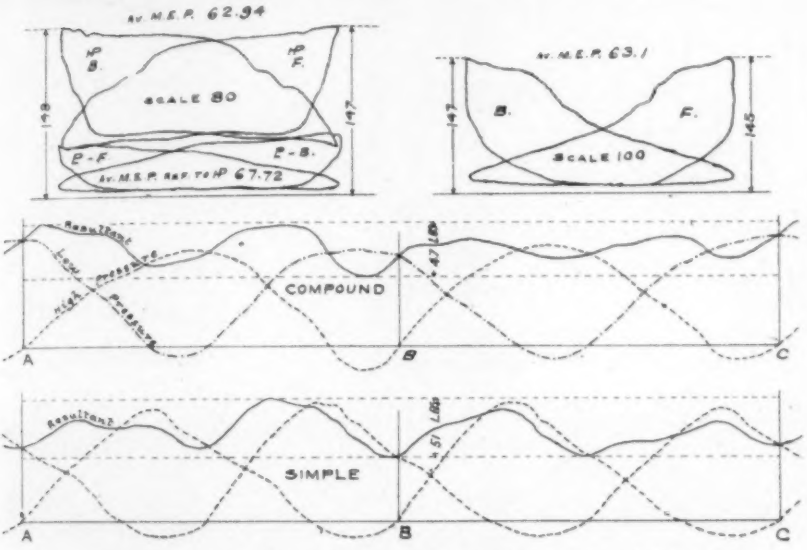
ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2" = 1 ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above ABC represent ROTATIVE EFFECTS, 1 in height equalling 80 lbs. per sq. in. of HP piston, exerted at Crank Pin at Right Angles to Crank.

ROTATIVE EFFECTS. PLATE XXXII

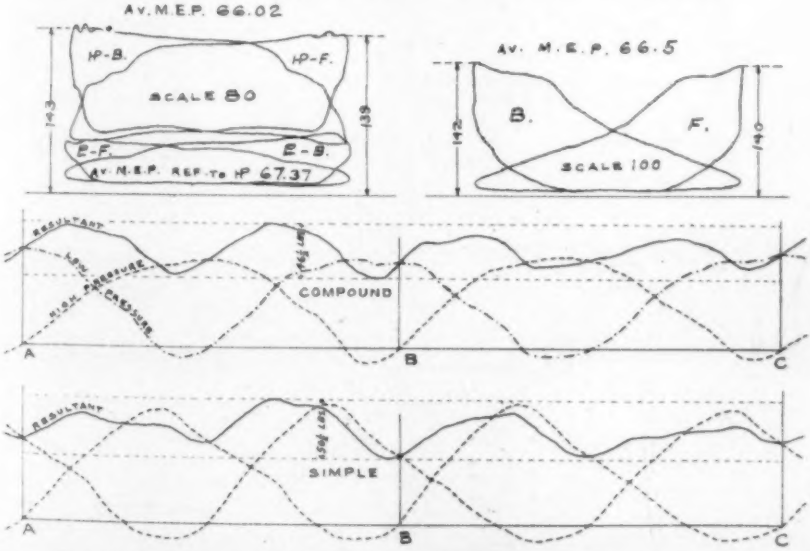
ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2" = 1ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above ABC represent ROTATIVE EFFECTS, 1" in height equalling 80 lbs. per sq. in. of HP piston, exerted at Crank Pin at Right Angles to Crank.

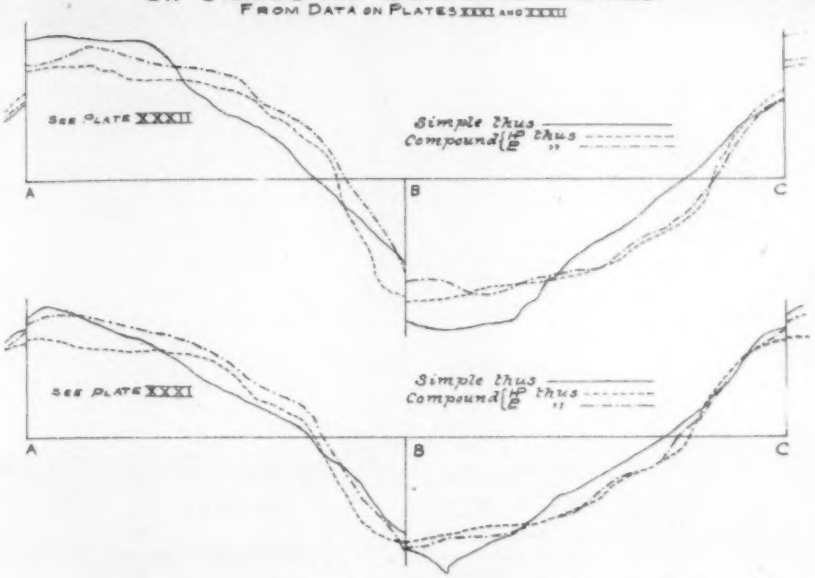
ROTATIVE EFFECTS PLATE XXXIII

ON SIMPLE AND COMPOUND ENGINES FROM ACTUAL CARDS
OF SIMILAR INITIAL STEAM PRESSURES AND MEAN EFFECTIVE PRESSURES.



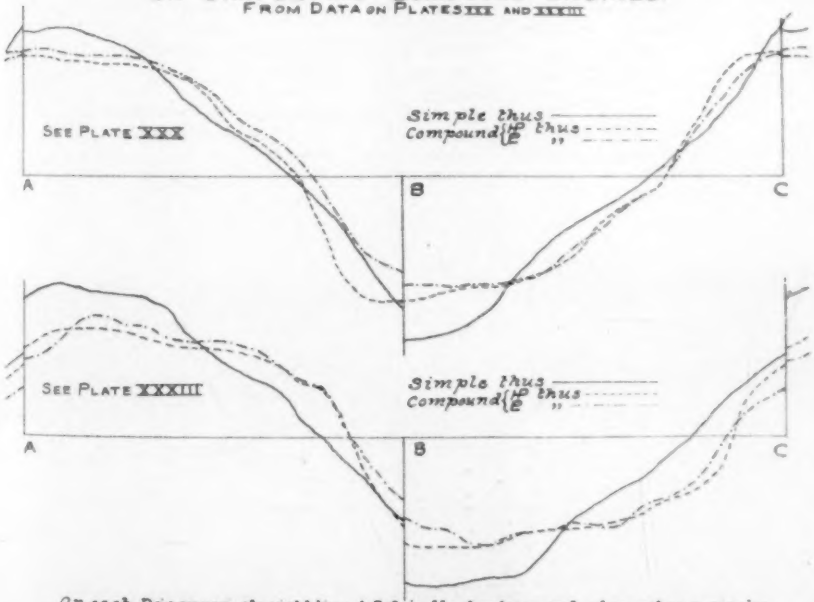
On each Diagram, straight line ABC is the development of Crank Pin Circle; scale, 2" = 1ft. A and C are at Back Dead Point of Left crank. B is at Forward Dead Point of Left crank. Heights above ABC represent ROTATIVE EFFECTS, 1" in height equalling 80 lbs. per sq. in. of HP piston; exerted at Crank Pin at Right Angles to Crank.

CRANK-PIN STRESS, PLATE XXXIV
ON SIMPLE AND COMPOUND ENGINES.
FROM DATA ON PLATES XXXI AND XXXII



On each Diagram, straight line A B C is the development of crank pin circle; scale 2" = 1 ft. A and C are at the back dead point; B is at the forward dead point. Vertical distances from A B C represent total force acting on crank-pin, due to steam-pressure; 1 in height equalling 80 lbs. per sq in. of HP piston. Distances above A B C correspond to pulls of the connecting-rod. Distances below A B C correspond to thrusts of the connecting-rod.

CRANK-PIN STRESS PLATE XXXV
ON SIMPLE AND COMPOUND ENGINES.
FROM DATA ON PLATES XXX AND XXXIII



On each Diagram, straight line A B C is the development of crank pin circle; scale 2" = 1 ft. A and C are at the back dead point; B is at the forward dead point. Vertical distances from A B C represent total force acting on crank pin, due to steam-pressure; 1 in height equalling 80 lbs. per sq in. of HP piston. Distances above A B C correspond to pulls of the connecting-rod. Distances below A B C correspond to thrusts of the connecting-rod.

TABLE No. 4.
LOCOMOTIVE DIMENSIONS.

ENGINE	COMPOUND 2600	SIMPLE N.Y.P.&B. 34	SIMPLE B.&A. 173 & 136
FUEL	SOFT COAL	SOFT COAL	SOFT COAL
CYLINDER - SIZES - R.S.	28" × 24"	18" × 24"	18" × 22"
" " - L.S.	15" × 24"	18" × 24"	18" × 22"
DRIVERS - DIAMETER	78"	72"	70"
BOILER "	52"	52"	52"
" - FLUES - O.D.	2"	2"	2"
" " - NUMBER	214	200	221
" " - LENGTH	10'-10"	11'-10⅝"	11'-0"
GRATE - STYLE	CAST IRON ROCKING	CAST IRON ROCKING	CAST IRON ROCKING
" - SIZE	78⅛" × 34⅜"	72⅛" × 34⅜"	71⅛" × 35¼"
" - AREA	18.65 SQ.FT.	17.72 SQ.FT.	17.41 SQ.FT.
HEATING SURFACE - TOTAL	1243.83 "	1236.63 "	1236.62 "
" " - FIRE BOX	157.57 " (INCLUDING 19.69 SQ.FT. FIRE BRICK TUBES)	120.95 "	116.78 "
" " - FLUES	1086.26 "	1115.68 "	1119.84 "
AREA RATIO - HEATING SURFACE TO GRATE	66.69	69.78	71.03
WEIGHTS - LOADED	103230 LBS.	91250 LBS.	91000 LBS.
" " - DRIVERS	66520 "	60200 "	61500 "
" " - TRUCK	36710 "	31050 "	29500 "

TABLE Nº. 5-A

GENERAL DATA AND RESULTS OF TESTS

ON

NEW YORK, PROVIDENCE AND BOSTON R. R.

SCHEDULE RUNNING TIME - TRAIN Nº. 23
PROVIDENCE TO NEW LONDON - 64 MLS. - 1 HR. 40 MINS.

SCHEDULE RUNNING TIME - TRAIN Nº 42
NEW LONDON TO PROVIDENCE - 1 HR. 41 MINS.

		TRAIN Nº. 23-WEST							TRAIN Nº. 42-EAST						
ENGINE	DATE-1891	RUNNING TIME FROM PROV. TO N. LONDON	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS			RUNNING TIME FROM N. LONDON TO PROV.	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS		COAL WEIGHED OUT TO ENGINE - POUNDS
N.Y.P.&B.-34	3/16	1:47	35.95	448		HOT BOX TRAIN LEFT 2 MINS. LATE			1:40	38.50	448		DELAYED BY TRAIN Nº. 183 TRAIN LEFT 10 MINS. LATE		86/7
	3/17	1:29	43.24	448		" " 17 " "			1:41	38.02	512		DELAYED BY TRAIN Nº. 184 TRAIN LEFT 10 MINS. LATE		9033
	3/18	1:40	38.55	448		" " ON TIME			1:36	40.0	448		DELAYED BY TRAIN Nº. 84 TRAIN LEFT 6 MINS. LATE		9082
				TOTAL 1344	TOTAL						TOTAL 1408	TOTAL	WEIGHED BACK		2134
													TOTAL AMT. COAL BURNED DURING TESTS		24838
COMPOUND-2600	3/19	1:40	38.55	448		TRAIN LEFT ON TIME			1:35	40.5	448		TRAIN LEFT 3 MINS. LATE (WITHHELD 2 MIN. TRAIN LEFT TO BE 10 MINS. LATER) 1 SLOW-UPS, 1 EXTRA STATION STOP		8682
	3/20	1:40	38.55	448		" " " "			1:42	37.64	448		2 SLOW-UPS, 1 EXTRA STATION STOP		8238
	3/21	1:39	38.76	448		" " 1 MIN. LATE			1:55	33.5	512		2 SLOW-UPS, 2 EXTRA STATION STOPS AND 2 SIGNAL STOPS NEAR PROVIDENCE		4416
				TOTAL 1344	TOTAL						TOTAL 1408	TOTAL	WEIGHED BACK		3000
													TOTAL AMT. COAL BURNED DURING TESTS		18338

Nº. OF REGULAR STOPS TRAIN Nº. 23-3

REGULAR SLOW-UPS AT TIME OF TESTS:-
ELMWOOD-ON ACCT. OF EXCAVATIONS
MYSTIC BRIDGE
NEW LONDON BRIDGE

Nº. OF REGULAR STOPS TRAIN Nº. 42-3

TABLE Nº. 5-B

SUMMARY

ENGINE NUMBER	TOTAL CAR MILEAGE	TOTAL COAL CONSUMPTION	AVERAGE AMOUNT OF COAL USED PER CAR MILE	PERCENTAGE OF COAL SAVED	AVERAGE RUNNING TIME PROV. TO N. LON.	AVERAGE RUNNING TIME N. LON. TO PROV.	AVERAGE MILES PER HOUR PROV. TO N. LON.	AVERAGE MILES PER HOUR N. LON. TO PROV.
34	2752	12.27 TONS	8.91 LBS.	———	1HR.-38.6 MINS.	1HR. 39 MINS.	39.25	38.88
2600	2752	9.17 "	6.66 "	25.2 %	1 " 39.6 "	1 " 44 "	38.63	37.21

TABLE Nº. 6-A

GENERAL DATA AND RESULTS OF TESTS

ON

NEW YORK, PROVIDENCE AND BOSTON R. R.

SCHEDULE RUNNING TIME - TRAIN Nº 39
PROVIDENCE TO NEW LONDON - 64 MLS. - 1 HR. 35 MINS.

SCHEDULE RUNNING TIME - TRAIN Nº 50
NEW LONDON TO PROVIDENCE - 1 HR. 35 MINS.

		TRAIN Nº. 39-WEST							TRAIN Nº. 50-EAST						
ENGINE	DATE-1891	RUNNING TIME FROM PROV. TO N. LONDON	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS			RUNNING TIME FROM N. LONDON TO PROV.	AVERAGE SPEED IN MILES PER HOUR	CAR MILEAGE	TRAIN WEIGHT EMPTY - TONS	REMARKS		COAL WEIGHED OUT TO ENGINE - POUNDS
N.Y.P.&B.-34	4/6	1:34	43.58	384		5 SLOW-UPS			1:25	45.77	384		4 SLOW-UPS		8316
	4/7	1:32	42.40	384		4 SLOW-UPS FIRE TURNED OVER AT ABOUT 8 O'CLOCK IN MORNING TO MOVE ENGINE AROUND SOME COAL WAS USED			1:30	43.10	384		2 SLOW-UPS 2 EXTRA STATION STOPS		7123
	4/8	1:30	43.10	384		3 SLOW-UPS			1:28	44.06	384		4 SLOW-UPS		4780
	4/9	1:28	44.06	384		4 " "			1:27	44.82	384		3 " "		4796
	4/10	1:32	42.20	384		4 " "			1:29	43.83	384		3 " "		4678
	4/11	1:33	41.72	384		5 " "			1:23	46.76	384		3 SLOW-UPS NIGHTTULE LEAKED QUITE BADLY FIRE BANKED TO KEEP TILL MONDAY		3945
				TOTAL 2304	TOTAL						TOTAL 2304	TOTAL	WEIGHED BACK		1832
													TOTAL AMT. COAL BURNED DURING TESTS		31806
COMPOUND-2600	4/20	1:26	45.36	384		3 SLOW-UPS			1:26	45.36	384		2 SLOW-UPS		7765
	4/21	1:33	41.93	384		4 SLOW-UPS FIRE TURNED OVER AT NOON TO MOVE ENGINE AROUND, THEN BANKED.			1:26	45.13	384		2 " "		3510
	4/22	1:26	43.56	384		3 SLOW-UPS FIRE TURNED OVER AT NOON TO COAL UP ENGINE, THEN BANKED.			1:26	45.13	384		2 " "		4485
	4/23	1:32	42.20	384		3 SLOW-UPS			1:30	43.33	384		2 " "		4328
	4/24	1:30	43.10	384		3 " "			1:31	42.87	384		2 " "		4618
	4/25	1:32	42.07	384		4 " "			1:28	47.27	384		2 " "		3774
				TOTAL 2304	TOTAL						TOTAL 2304	TOTAL	WEIGHED BACK		1667
													TOTAL AMT. COAL BURNED DURING TESTS		27193

Nº. OF REGULAR STOPS TRAIN Nº. 39-1.

Nº. OF REGULAR STOPS TRAIN Nº. 50-1

TABLE Nº. 6-B

SUMMARY

ENGINE NUMBER	TOTAL CAR MILEAGE	TOTAL COAL CONSUMPTION	AVERAGE AMOUNT OF COAL USED PER CAR MILE	PERCENTAGE OF COAL SAVED	AVERAGE RUNNING TIME PROV. TO N. LOND.	AVERAGE RUNNING TIME N. LOND. TO PROV.	AVERAGE MILES PER HOUR PROV. TO N. LOND.	AVERAGE MILES PER HOUR N. LOND. TO PROV.
34	4608	159 TONS	69 LBS.	———	1HR. 31 MINS.	1HR. 27.3 MINS.	42.84	44.72
2600	4608	13.59 "	5.9 "	14.52 %	1 " 30.7 "	1 " 27 "	43.04	44.84

WATER ACCOUNT	ENGINE NUMBER	EVAPORATED IN BOILER	USED IN CYLINDERS	POUNDS EVAPORATED PER POUND OF COAL	PERCENTAGE WATER SAVED, USED IN CYLINDERS
	34	25140 GALLONS	25087 GALLONS	6.54 LBS. FROM 43.5°	———
	2600	23812 "	23706 "	7.30 " " 59.25°	5.5 %

TABLE No. 7-A
GENERAL DATA AND RESULTS OF TESTS
ON
BOSTON AND ALBANY R.R.

Schedule Running Time – Train No. 19
Boston to Worcester – 44 miles – 65 mins.
Worcester to Charlton – 13.5 " – 24 "
Charlton to Springfield – 41 " – 65 "
Boston to Springfield – 98.5 " – 2 hrs. 35 mins.

Schedule Running Time – Train No. 18
Springfield to Charlton – 74 mins.
Charlton to Worcester – 23 "
Worcester to Boston – 70 "
Springfield to Boston – 2 hrs. 44 mins.

TRAIN No. 19 – WEST

Engine	Date – 1891	Running Time in Minutes: Boston to Worcester	Worcester to Charlton	Charlton to Springfield	Actual Running Time Boston to Springfield	Average Speed in Miles per Hour	Car Mileage	Train Weight Empty – Tons	Causes of Delay
Compound-2600	7/3	71	25	60	2:36	37.88	492.5	158.4	FREIGHT AT SO. FRAMINGHAM
	7/4	69	23	64	2:36	37.88	394	131	
	7/5	69	24	63	2:36	37.88	394	131	
	7/6	71	24	61	2:36	37.88	436	141.8	SIGNALS SLOW-UP NEAR WORCESTER
	7/7	71	25	70	2:46	35.66	394	131	SIGNAL & SLOW-UP AT SO. FRAMINGHAM, SWITCHBACK TO OTHER MAIN NEAR SPRINGFIELD
	7/8	69	25	62	2:36	37.88	394	131	FREIGHT NEAR CHARLTON
	7/9	72	23	62	2:37	37.54	394	131	FREIGHT AT WORCESTER
	7/10	71	25	60	2:36	37.88	394	131	SLOW-UP AT WORCESTER
	7/11	72	26	62	2:40	37.03	492.5	158.4	SIGNAL AT WORCESTER STOP PROCEEDS AT CHARLTON
B. & A. 136	6/24	70	24	65	2:39	37.17	394	131	WAIT FOR ORDERS AT WORCESTER & CHARLTON
	6/25	70	22	64	2:36	37.88	394	131	WAIT FOR ORDERS AT WORCESTER
	6/26	70	27	59	2:36	37.88	394	131	SLOW-UPS AT WORCES.
	6/27	72	25	61	2:38	37.40	492.5	158.4	WAIT FOR ORDERS AT WORCESTER
	6/28	72	22	63	2:37	37.54	394	131	SIGNALS AT WORCESTER
	6/29	70	24	62	2:36	37.88	394	131	SLOW-UP AT WORCESTER
	6/30	69	22	63	2:34	38.47	394	131	
	7/1	70	23	64	2:37	37.54	394	131	WAIT FOR ORDERS AT WORCESTER
	7/2	69	23	64	2:36	37.88	394	131	

No. of Regular Stops Train 19 – 1.

TRAIN No. 18 – EAST

Springfield to Charlton	Charlton to Worcester	Worcester to Boston	Actual Running Time Springfield to Boston	Average Speed in Miles per Hour	Car Mileage	Train Weight Empty – Tons	Causes of Delay	Coal Consumption per Round Trip – Tons
64	23	69	2:36	37.71	591	182.9		3.5
71	23	69	2:43	36.26	591	182.9	HOT BOX ON CAR NEAR BOSTON	3.5
74	23	68	2:45	35.81	684.6	210.3	SWITCH ENG. AT BOSTON	3.5
73	23	70	2:46	35.66	492.5	144.9		3.5
69	24	68	2:41	36.71	492.5	144.9		3
70	23	65	2:38	37.45	492.5	144.9	WORCESTER TO SIGNAL AT TOWER 6	3.5
72	23	69	2:44	36.08	492.5	144.9		3
73	23	70	2:46	35.66	492.5	144.9		2.5
72	23	67	2:42	36.48	492.5	144.9		3
73	23	65	2:41	36.71	591	182.9		4
72	23	64	2:44	36.08	492.5	144.9		5
69	23	65	2:37	37.54	591	182.9		4
71	23	70	2:44	36.08	492.5	144.9		5.5
74	23	70	2:47	35.43	492.5	144.9		4
71	25	70	2:44	36.08	492.5	144.9		4.5
73	23	70	2:46	35.66	492.5	144.9		3.5
74	23	67	2:44	36.08	591	182.9		4
72	23	64	2:44	36.08	492.5	144.9		5

No. of Regular Stops Train 18 – 2.

TABLE No. 7-B
SUMMARY

Engine Number	Total Car Mileage	Total Coal Consumption	Average Amt. of Coal Used per Car Mile	Percentage of Coal Saved	Average Running Time: Bos. to Spring.	Spring. to Bos.	Average Miles per Hour: Bos. to Spring.	Spring. to Bos.
2600	8613.5	29 Tons	6.73 Lbs.	28.63 %	2 hrs. 37½ mins.	2 hrs. 34½ mins.	37.51	36.32
136	8372.5	39.5 "	9.43 Lbs.	——	2 " 36½ "	2 " 43½ "	37.75	36.2

TABLE No. 8-A
GENERAL DATA AND RESULTS OF TESTS
ON
BOSTON AND ALBANY R.R.

Schedule Running Time – Train No. 83
Boston to Worcester – 44 mins. – 70 mins.
Worcester to Charlton – 13.5 " – 24 "
Charlton to Springfield – 41 " – 64 "
Boston to Springfield – 98.5 " – 2 hrs. 41 mins.

Schedule Running Time – Train No. 50
Springfield to Charlton – 64 mins.
Charlton to Worcester – 22 "
Worcester to Boston – 68 "
Springfield to Boston – 2 hrs. 41 mins.

TRAIN No. 83 – WEST

Engine	Date – 1891	Running Time in Minutes: Boston to Worcester	Worcester to Charlton	Charlton to Springfield	Actual Running Time Boston to Springfield	Average Speed in Miles per Hour	Car Mileage	Train Weight Empty – Tons	Causes of Delay
Compound-2600	7/14	77	24	57	2:38	37.40	635	190.5	SWITCHBACK TO OTHER MAIN AT SO. FRAM.
	7/15	70	23	65	2:38	37.40	591	180	SWITCHBACK TO OTHER MAIN AT SPRINGFIELD
	7/16	70	25	62	2:37	37.59	591	180	
	7/17	73	23	59	2:37	37.54	591	180	SLOW-UP SET. SO. FRAM. & WORCESTER
	7/18	71	24	62	2:37	37.59	591	180	
	7/20	70	25	62	2:37	37.59	591	180	
	7/21	73	24	61	2:38	37.45	591	180	
B. & A. 173	7/6	71	26	61	2:38	37.45	688.5	207.4	
	7/7	71	25	61	2:37	37.59	591	180	TRAIN OF 7½ CHOSEN AS ENGINE NOT ANOTHER TRAIN ON 7/7
	7/8	70	24	64	2:38	37.45	591	180	
	7/9	70	24	64	2:38	37.40	591	180	
	7/10	73	24	61	2:38	37.45	591	180	
	7/11	72	23	61	2:36	37.88	591	180	
	7/13	72	23	61	2:34	37.88	591	180	

No. of Regular Stops Train 83 – 1.

TRAIN No. 50 – EAST

Springfield to Charlton	Charlton to Worcester	Worcester to Boston	Actual Running Time Springfield to Boston	Average Speed in Miles per Hour	Car Mileage	Train Weight Empty – Tons	Causes of Delay	Coal Consumption per Round Trip – Tons
73	21	65	2:39	37.17	612.25	181.9	SIGNAL SET. SPRING & CHARL.	4
70	22	67	2:39	37.17	612.25	181.9	2 SIGNAL STOPS (ROAR CHAR. SLOW-UP AT WILBRAHAM) FOR SINGLE TRACK	3.5
69	22	68	2:39	37.17	612.25	181.9	SLOW-UPS SET. SPRING. & CHARLTON – 3 SIGNAL STOPS SET. WORCESTER & SO. FRAMINGHAM	3
72	22	68	2:39	37.45	612.25	181.9	SIGNAL SET. SO. FRAM. & SLOW-UPS & SIGNALS SET. SPRING. & CHARLTON	3
70	22	64	2:36	37.88	710.5	215.3	WAIT FOR ORDERS AT WORCESTER	3
72	22	69	2:43	36.26	612.25	181.9	ARRIVED 30 MINS. BY REASON OF TRAIN 48 NEAR SO. FRAM. FROM SIGNAL STOPS. PASSED SPRING. & CHARL. PASSED BY FREIGHT AT BOSTON	3.5
71	22	66	2:39	37.17	612.25	181.9	3 SLOW-UPS & 2 SIGNALS SET. SPRING. & CHARLTON	3.5
70	22	70	2:42	36.48	809	242.7		5
69	22	67	2:38	37.45	612.25	181.9		4.5
70	22	67	2:39	37.17	612.25	181.9		4
71	20	65	2:36	37.88	612.25	181.9		4
69	22	65	2:36	37.88	612.25	181.9		4
69	22	67	2:38	37.45	612.25	181.9		4.5
69	22	67	2:38	37.40	612.25	181.9		4.5

No. of Regular Stops Train 50 – 4.

TABLE No. 8-B
SUMMARY

Engine Number	Total Car Mileage	Total Coal Consumption	Average Amt. of Coal Used per Car Mile	Percentage of Coal Saved	Average Running Time: Bos. to Spring.	Spring. to Bos.	Average Miles per Hour: Bos. to Spring.	Spring. to Bos.
2600	8865	23.5 Tons	5.48 Lbs.	21.6 %	2 hrs. 37.4 mins.	2 hrs. 39 mins.	37.53	37.18
173	8716	30.5 "	8.99 "	——	2 " 37½ "	2 " 38 "	37.59	37.39

Diagram of Intercepting Valve — by R.I. Locomotiv

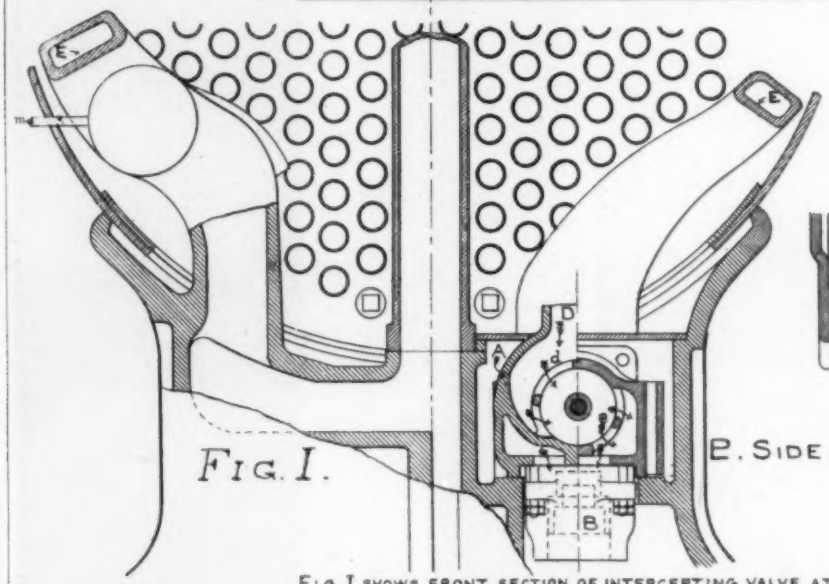


Fig. I.

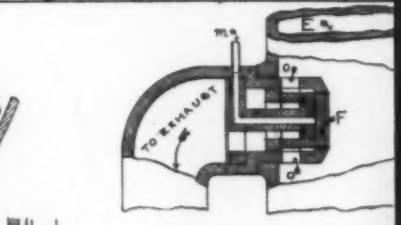


Fig. II.

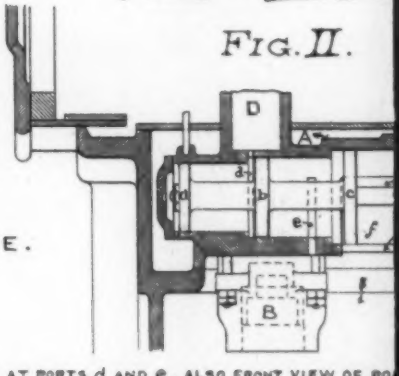


Fig. I shows front section of intercepting valve at ports d and e, also front view of po

Fig. II shows side section of same while running compound. Fig. III shou

A (in fig's I-II-III) intercepting valve casing. — B (in fig's I-II-III) reducing valve. — C (in fig. II) oil dash pot. — D (in fig's I-II) pipe from main steam pipe t

a-b-c (in fig's II-III) intercepting valve piston. d (in fig's I-II-III) port from D through A. e (in fig's I-II-III) port from A into the reduci

m (in figs I-II-III) small pipe and passage connecting hand valve in cab to chamber h. o (in

The device shown above operates as follows:

The intercepting valve being in any position as in fig. II, and the exhaust valve closed as in fig. II, the throttle being opened; boiler steam will pass to the H.P. cylinder in the usual manner, and also through pipe D into the intercepting valve A, causing the piston to move into the position shown in fig. III. In this position the receiver is closed to the L.P. cylinder by the piston C, and steam from D passes through ports d and e, and reducing valve B, into the L.P. steam chest; the pressure being reduced from boiler pressure in the ratio of the cylinder areas. The piston a-b-c, is so proportioned that it will automatically change to the compound position shown in fig. II, when a predetermined pressure in the receiver E has been reached by exhausts from the H.P. cylinder. The engine thus starts with steam in both cylinders, and automatically changes to compound at a desired receiver pressure.

The engine may be changed from the compound system to the simple at any time, at the will of the engineer, by opening the valve F connecting the receiver to the exhaust pipe, nozzle in the usual

The exhaust val in cab connecting it to m is in connection position as per fig. valve F as in fig. III either position a

It is obvious t may be operated opening the exha piston a-b-c will as described in th

/E — BY R.I. LOCOMOTIVE WORKS. PATENTED SEPT. 22. 91.

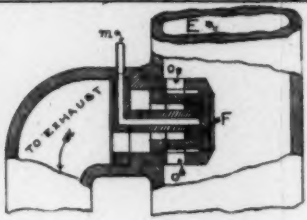
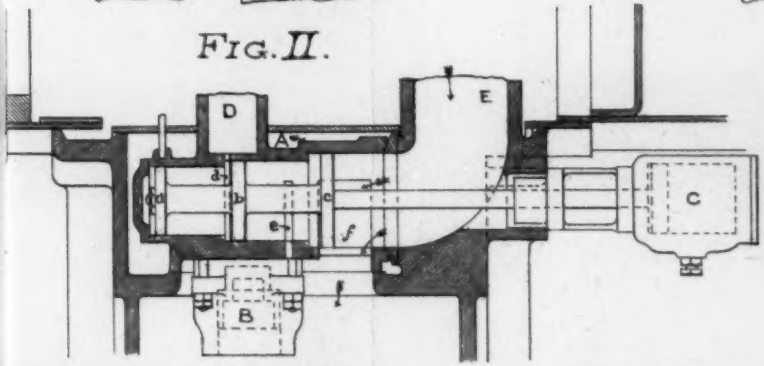


FIG. II.



PORTS d AND e, ALSO FRONT VIEW OF PORTION OF RECEIVER WITH EXHAUST VALVE.
NING COMPOUND. FIG. III SHOWS SAME WHILE RUNNING SIMPLE.
- D (IN FIG'S I-II) PIPE FROM MAIN STEAM PIPE TO INTERCEPTING VALVE. - E (IN FIG'S I-II-III) THE RECEIVER. - F (IN FIG'S I
B (IN FIG'S I-II-III) PORT FROM A INTO THE REDUCING VALVE B. f (IN FIG'S II-III) PORT FROM A INTO PASSAGE TO E S
N CAB TO CHAMBER h. o (IN FIG'S II-III) PORT THROUGH EXHAUST VALVE CASING.

D AS IN FIG. II,
, AND ALSO
N IN FIG. III.
D PASSES
G REDUCED
IS SO PRO-
WN IN FIG. II,
USTS FROM
RS, AND

E AT ANY
RECEIVER

TO THE EXHAUST PIPE, ALLOWING THE EXHAUSTS FROM THE H.P. CYLINDER TO ESCA
NOZZLE IN THE USUAL MANNER.

THE EXHAUST VALVE F IS OPERATED AS FOLLOWS :—THE SMALL PIPE m IS FR
IN CAB CONNECTING IT TO EITHER STEAM OR ATMOSPHERE. WHEN DESIRING TO RU
m IS IN CONNECTION WITH ATMOSPHERE, THE RECEIVER STEAM KEEPING
POSITION AS PER FIG. II. TO RUN SIMPLE m IS CONNECTED TO STEAM WHICH
VALVE F AS IN FIG. III, THE PORTS o OPENING E TO THE EXHAUST. THE
EITHER POSITION AT ANY TIME AT THE WILL OF THE ENGINEER.

IT IS OBVIOUS THAT, IN CASE OF BAD CONDITIONS OF STARTING,
MAY BE OPERATED AS A SIMPLE ONE AT THE WILL OF THE
OPENING THE EXHAUST VALVE BEFORE STARTING, AND THAT UPON
PISTON a-b-c WILL AUTOMATICALLY TAKE THE COMPOUND POSI
AS DESCRIBED IN THE FIRST PARAGRAPH.

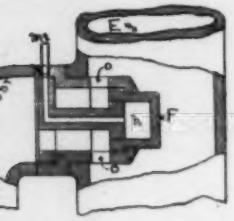
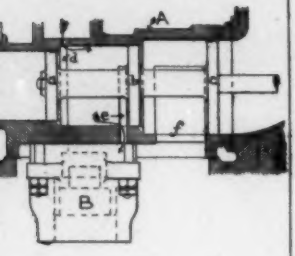


FIG. III.



.– F (IN FIG'S II-III) EXHAUST VALVE.
ASSAGE TO E STEAM CHEST.
.

ER TO ESCAPE THROUGH THE

PIPE m IS FROM A HAND VALVE
ING TO RUN COMPOUND,
AM KEEPING VALVE F IN
EAM WHICH WILL HOLD THE
ST. THE VALVE F TAKES
ENGINEER.
TARTING, THE ENGINE
OF THE ENGINEER BY
HAT UPON ITS CLOSURE THE
UND POSITION OF FIG. II,

APPENDIX II.

(*A*) CONTAINING THE DATA AND DESCRIPTIVE MATTER RELATING TO EXISTING INVENTIONS AND MECHANISMS, DEVISED BY OTHERS FOR OPERATING TWO CYLINDER COMPOUNDS—PUBLISHED AT HOME AND ABROAD—TOGETHER WITH THE EXPERIENCE AND OPINIONS OF THE MEMBERS OF THE COMMITTEE ON COÖRDINATE BRANCHES OF THE SUBJECT.

"The locomotive is not the invention of one man, but of a nation of mechanical engineers."
—ROBERT STEPHENSON.

The pen of locomotive history has recorded little or nothing of practical value during the first twelve centuries of our era.

Whether the announcement of M. Pambour, made in the year 1835, that "locomotive engines were the first of all engines," be true or not, we can refer with confidence to the words of Roger Bacon, written more than 600 years ago, in which he says: "We will be able to propel carriages with incredible speed without the assistance of any animal."

The long years succeeding this prophecy were filled with "speculations wild and visionary theories absurd" (so the records tell us), down to the date of Ramsay's English patent in 1618, which, in the quaint language of the time, offers us: "*A farre more easie and better waye for the carrying of coaches, carts, drayes and other things, going on wheels, than ever yet was used or discovered.*"

Even the great Sir Isaac Newton, in the year 1680, tries his hand at inventing a road locomotive, but whether it ever passed beyond "the idea only for other minds to work upon," history is silent.

The period of fruitful experiment with locomotive engines having cylinders and pistons and the necessary valve gear with linkages to cranks, begins with a French engineer, named Cugnot, in the years 1763 to 1770, and was continued by Murdock in 1784, and by Trevithick and Vivian in 1800, who at once solved the problems of high-pressure steam and simplicity of construction. Our "Watt of America"—Oliver Evans—in 1804, built that odd machine which was at home on land or in water, and, in common with Murdock, used the "grasshopper engine," with vertical steam cylinder.

Gurney's steam coach of 1828 is interesting as showing a horizontal cylinder having rod connections from a piston to a cranked driving-wheel axle, upon which is an eccentric for working the valve, arranged for cutting off at half stroke and with a link for reversing. He also used one of the earliest "sectional boilers," in which he carried steam of seventy pounds pressure per square inch.

But when the celebrated Rainhill trial came off in October 6, 1829, Stephenson's "Rocket" held the track alone, having more than performed all the stipulated conditions. This was the result of Stephenson's resolve in 1813 to make himself thoroughly acquainted with what had already

been done, and of subsequent application to accomplish the grand object of inventing an efficient and economical working locomotive.

Much of this history was, of course, interlined with inventions, which, like pure intents, came to nothing; many were worthily conceived, but were bad in construction, and for want of proper tools and ripeness of time were never repeated.

Stephenson's "Rocket" achieved a great victory, impressing the assembled multitude, on the occasion of the great trial, as well as the people throughout the whole kingdom. It ushered in a widespread railway mania, taking precedence over every other enterprise.

"Nothing will beat the locomotive," says Stephenson, "for efficiency in all weathers, for economy in drawing loads and for power and speed as occasion may require." We need not ask as to the fulfilment of Stephenson's prediction. It is everywhere, in every country, amply verified.

The locomotive, with two equally sized high-pressure cylinders, improved and perfected from the Stephenson model, which "held the road" in his day, is well nigh the universal type of our time.

Let us right here be particular in our statements regarding the earliest conception and development of the two-cylinder compound steam engine. There have been many opinions published concerning the origin of this important invention. We make no further apology, therefore, for setting this matter aright, and quote Mr. Wm. Pole's conclusions from his thorough study and publication of them in *Newton's London Journal of Arts*, for August, 1863:

"The double-cylinder engine was invented by Jonathan Hornblower, a mechanical engineer of considerable eminence in Cornwall, who took an important part in the application of the steam engine in that district, during the early part of Watt's career. The idea appears to have occurred to him early in the year 1776, if not before.

"He experimented upon a large working model. The cylinders of which were eleven and fourteen inches diameter, respectively; and he published his invention in 1781, describing it as consisting in the employment of two steam cylinders—the steam after it had acted in the first cylinder being employed a second time in the other, by permitting it to expand itself; the two cylinders being connected together by suitable steam ports and valves. At the same time, he described also, shortly but clearly, several other inventions relating to the steam engine. One referring to surface condensing, which is so much applied in modern days; others to means of getting rid of the air and condensing water; and another invention was a steam piston, which altered into a steam stuffing-box, is in common use at the present time. Here, therefore, was clearly developed the theoretical principle as well as the practical application of the expansion of steam; and it is beyond dispute that the first publication of the principle to the world was this of Hornblower's."

Dr. Thurston, in his *Growth of the Steam Engine*, says: "Richard Trevithick was the first engineer to apply steam power to the haulage of loads on the railroad."

Mr. Samuel Smiles, in his *Lives of the Stephensons*, recorded the following important departure from almost universal previous practice: "In Trevithick's engine, the piston was not only raised, but was depressed by the action of the steam, being in this respect an entirely original invention and of great value."

"Mr. Trevithick knew of Mr. Hornblower's double-cylinder engine in the year 1792; he had spoken to Davies Gilbert in 1796 on the possibility of making an engine to work by the force of steam."

"An old account book of Trevithick's, dated 1800, gives the detail items in the manufacture of the first steam carriage." "It was in progress in 1800, and on Christmas-eve, 1801, conveyed the first load of passengers ever moved by the force of the steam."

"Trevithick's high-pressure engine, which was worked by the force of steam, sixty pounds or more to the square inch.

"One of the gains from the Trevithick's high-pressure engine was its portability and cheapness.

"This engine had little or no resemblance to any steam engine that had preceded it.

"The boiler was cylindrical, in which the steam cylinder was fixed; the tubular boiler flues were of wrought iron, and entirely within the boiler.

"The exhausted steam having done its work in the cylinder, at a pressure of sixty pounds to the inch, passed into the chimney as a steam blast, causing an intensely hot fire, and in its passage heated the feed water.

"A patent was granted on the 24th of March, 1802, to Richard Trevithick and Andrew Vivian, for steam engines for propelling carriages, etc., which may be read and studied by the young engineer with pleasure and profit, even in this age of greatly-improved steam mechanism."

Mr. Trevithick, in the year 1802, made engines having two steam cylinders, which were connected to cranks at right angles, and they used the "blast-pipe;" such engines were called "puffers."

These engines were the first of the high-pressure double-cylinder type used in Cornwall. Mr. Trevithick's patent of 1802 recommends the use of two cylinders.

"The specification of the patent granted to Messrs. Trevithick and Vivian is descriptive of a high-pressure engine, the most simple and effective ever known." "It exhibits in construction the most beautiful simplicity of parts, the most sagacious selection of appropriate forms, their most convenient and effective arrangement and connection; uniting strength with elegance, the necessary solidity with the greatest portability, possessing unlimited power, with a wonderful pliancy to accommodate it to a varying resistance; it may, indeed, be called *the steam engine*."

From D. K. Clark's *The Steam Engine*, 1890, vol. iv, p. 647, we take a few paragraphs containing important references:

"It appears that the receiver type of engine was introduced and brought prominently forward by Mr. E. A. Cowper, who states that 'about the year 1838, a small steamboat, the *Era*, had a high- and low-pressure cylinder, with a pipe connecting them and cranks at right angles.'"

From Mr. Thomas Craddock's book, called *The Chemistry of the Steam Engine*, published in London in 1848, we make the following extracts:

On p. 51 he says: "Owing to the superiority, as it appears to me of two cylinders instead of one for the most economical use of steam expansively, I turned my attention to the combining in the simplest and most compact manner these two cylinders, so as to prevent as little loss of steam, by cooling and useless expansion between the two cylinders as possible. For this purpose I devised what I would designate the *twin-cylinder engine*, having one valve serving for the ingress and egress of the steam into both cylinders. By this means we make *one* eccentric, *one* valve, *one* cross-head, and *one* connecting-rod, with *one* steam-box, serve the purpose of both cylinders."

In the month of April and year 1844, Mr. Craddock made experiments with a compound engine of his own designing, which he says is "the *first* engine ever constructed on the principles I am here treating of, which are those of condensing by *air* with the production of a *vacuum*."

The extent of the vacuum obtained by these means—a revolving fan wheel—was eighteen inches.

"On the application of the invention under discussion to locomotive engines, I have thought much, as we had at one time determined on constructing a locomotive upon the principles I have set forth."

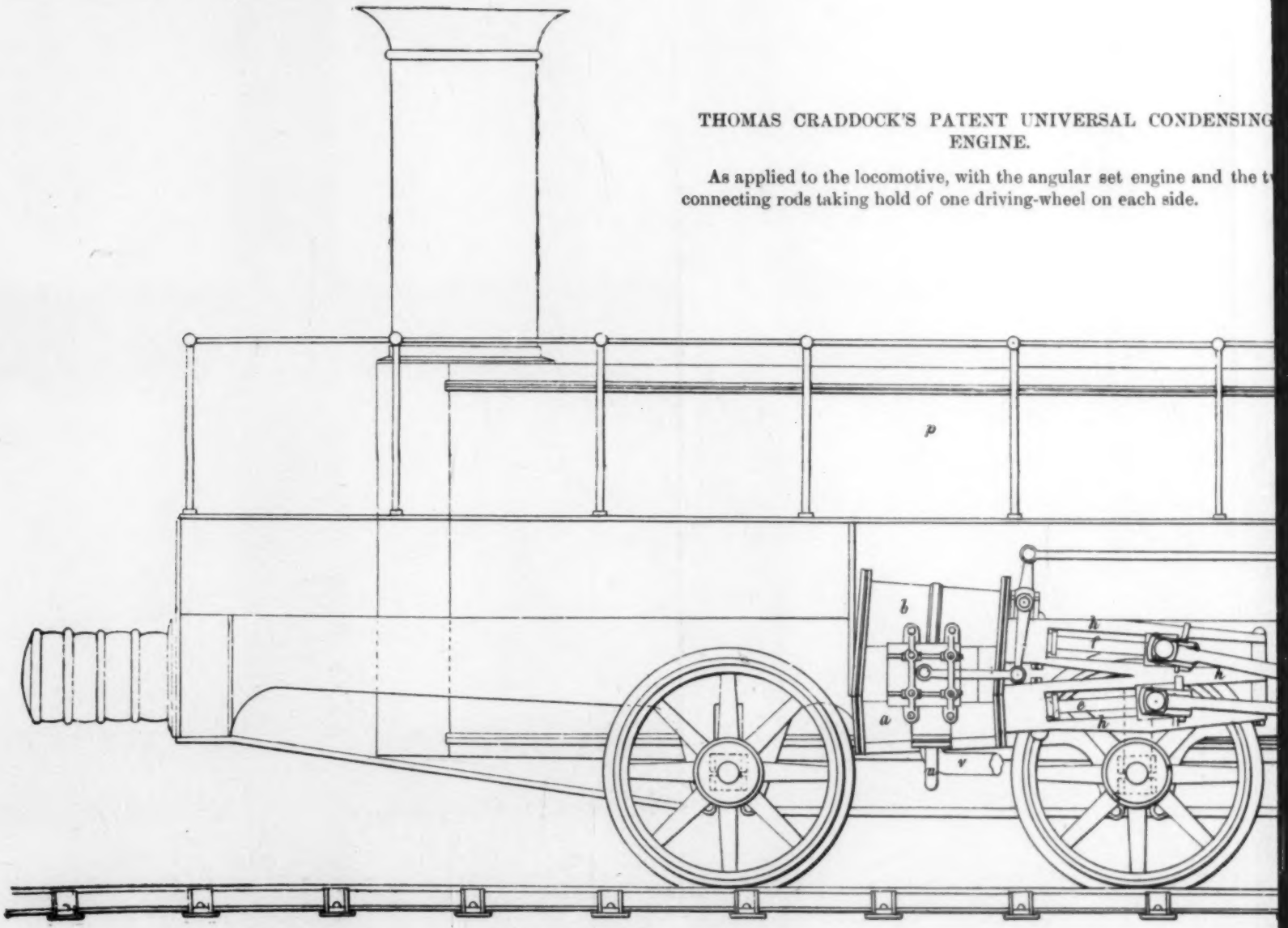
"The best mode, as it appears to me, of applying these principles for locomotive purposes, would be to construct a tubular boiler, having several ranges of tubes." * * * "I should also propose that, to insure the most economical use of the steam, the *twin cylinders*, of which I have before spoken, be fixed much in the same way as the cylinders are at present. We should then have a combination of the high- and low-pressure engine moving itself and a train along our railway." "Another thing to be desired, which would result from such locomotives, as I am here speaking of (with air condensation and return of condensed steam to the boiler again) is, that we should have no noise from, or even *appearance* of steam."

Mr. Craddock further states that, with his twin engine of six and fourteen-inch cylinders combined with his air condenser, by which he obtained a twenty-four inch vacuum, thus realizing his anticipations; he also performed a double quantity of work with the same quantity of steam. "I have fixed upon 115 pounds as the pressure of steam in the boiler, because that is the pressure I have used. But many years will not pass before 200 pounds pressure per square inch will be used, and this with almost total exemption from danger."

Mr. Craddock's patent universal condensing steam engine bears date the 3d of December, 1846, and embodies a claim for the adaptation of double-cylinder engines, attached to separate cranks, to railway locomotives, and a claim for the adaptation of the angularly-set double-cylinder engine, attached to a single crank, to railway locomotives. He further says more specifically, "I claim, in relation to all that class of high-pressure engines in which steam of a high pressure is used in one small

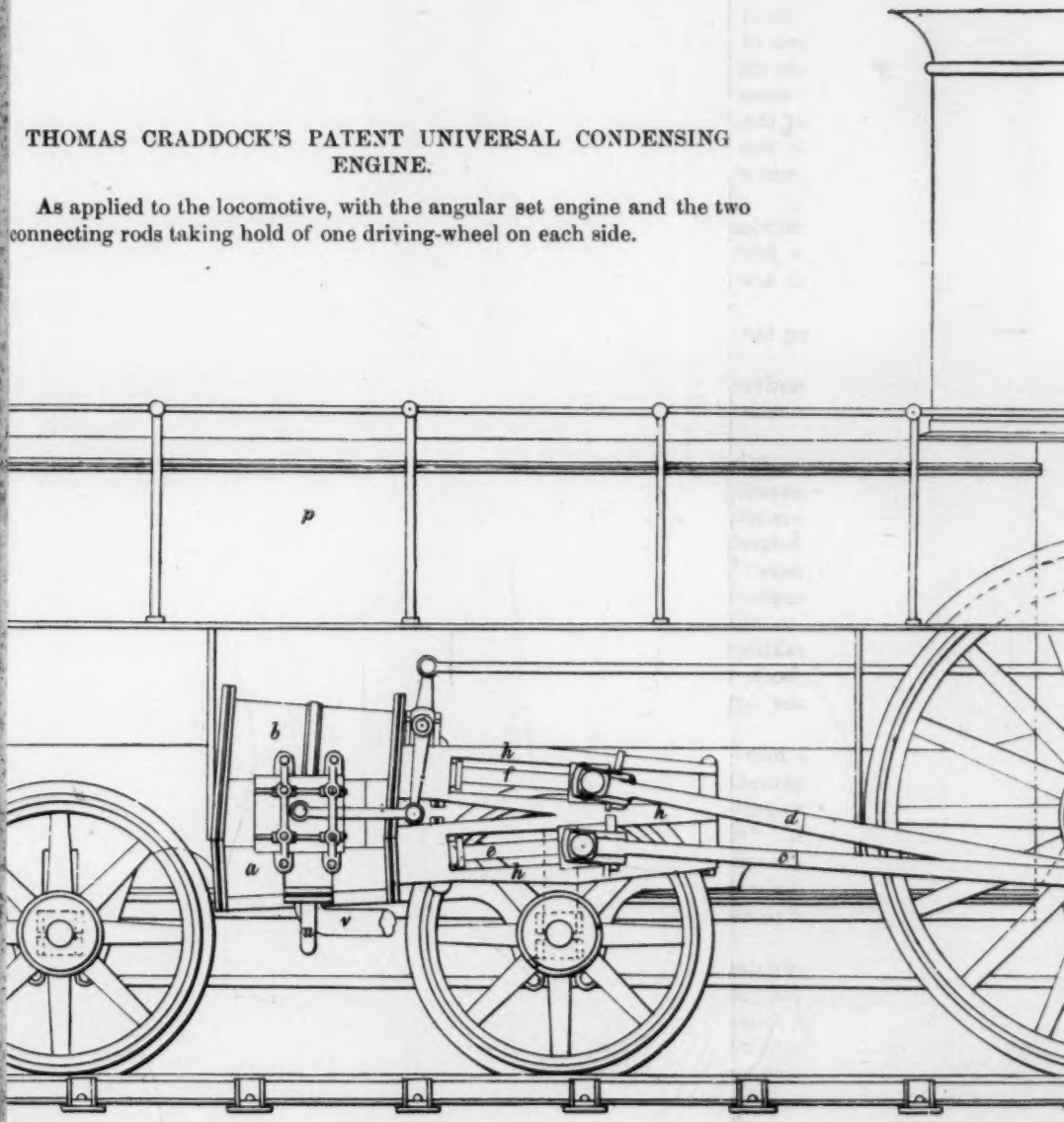
THOMAS CRADDOCK'S PATENT UNIVERSAL CONDENSING ENGINE.

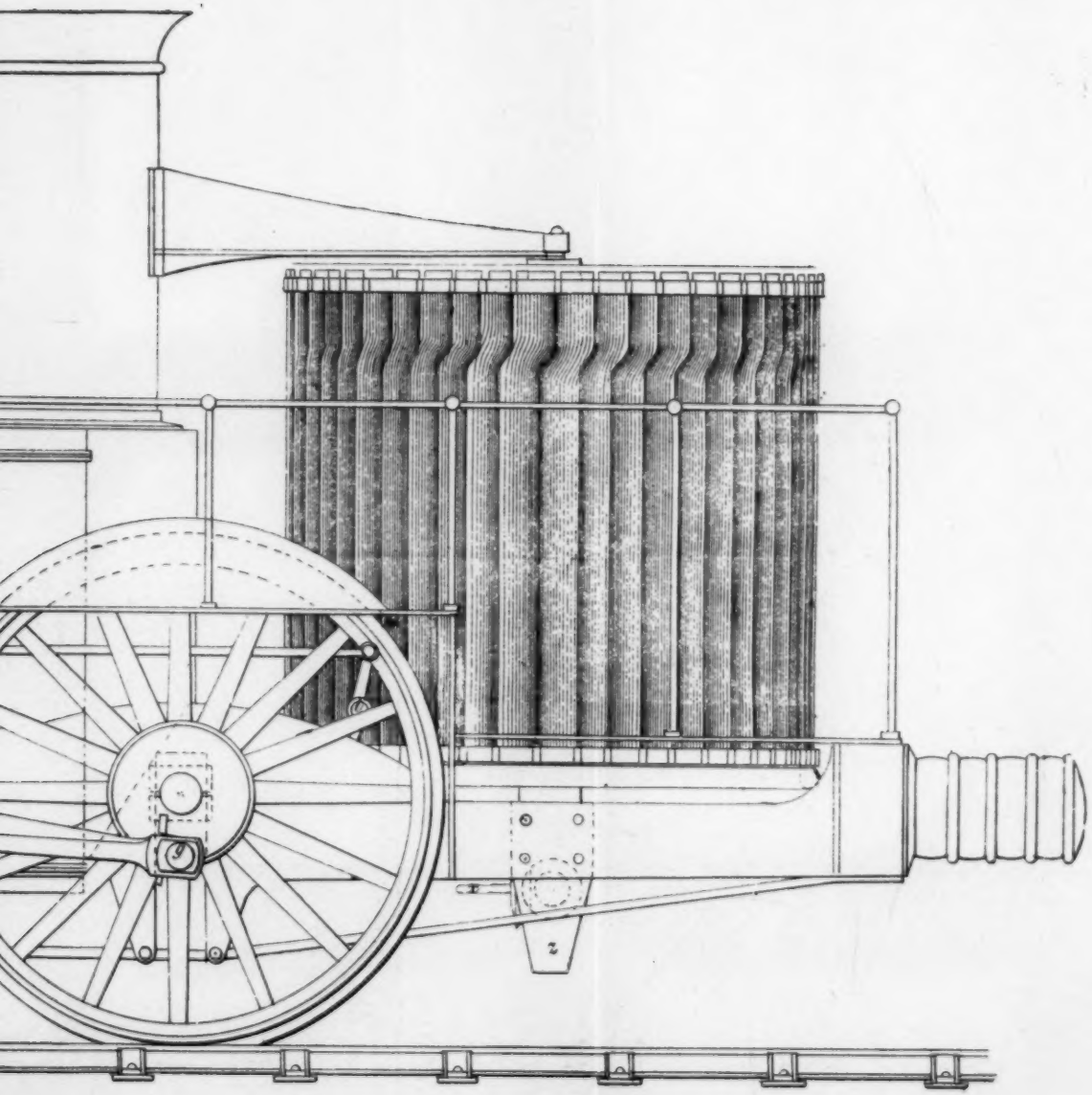
As applied to the locomotive, with the angular set engine and the t
connecting rods taking hold of one driving-wheel on each side.

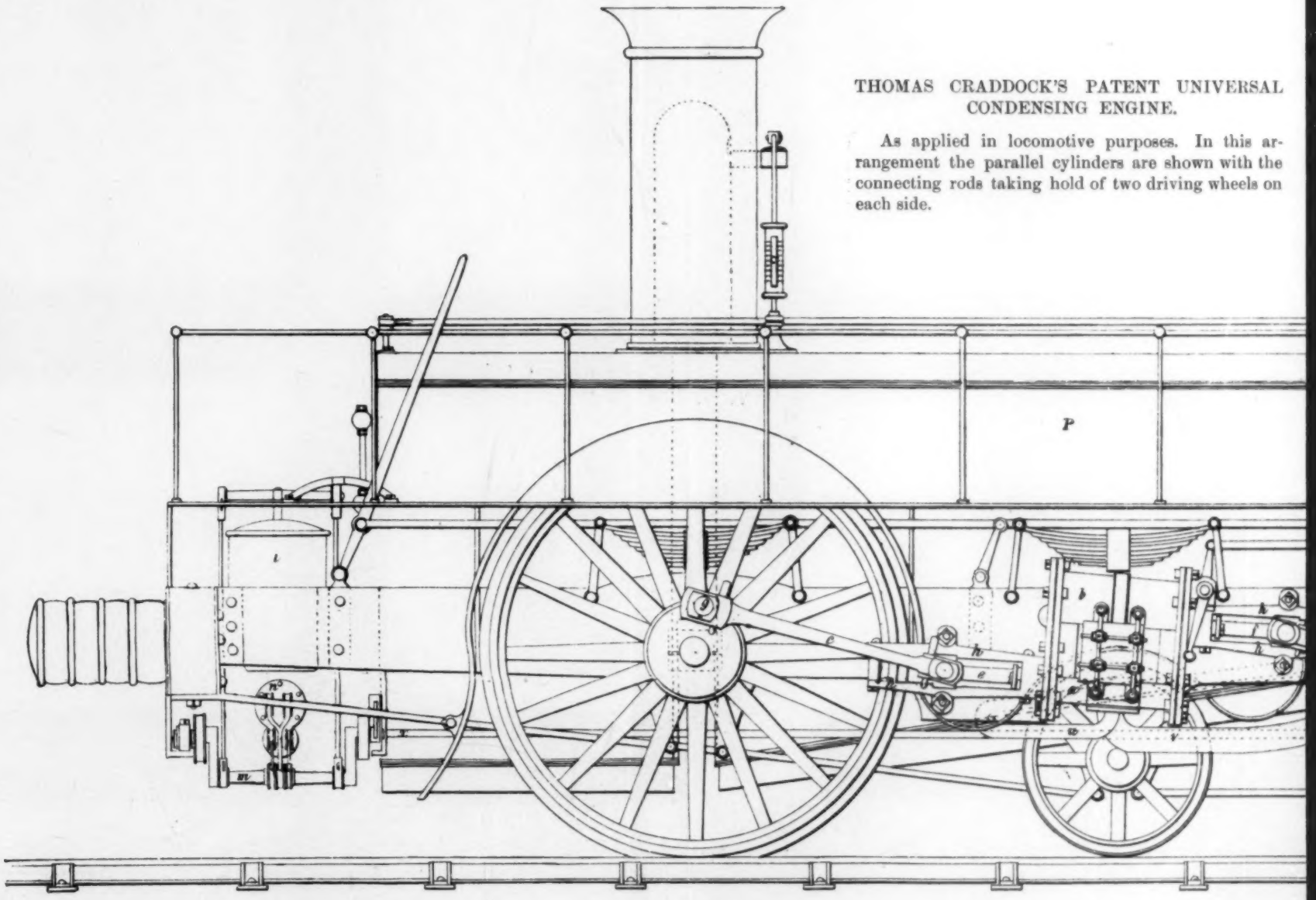


THOMAS CRADDOCK'S PATENT UNIVERSAL CONDENSING ENGINE.

As applied to the locomotive, with the angular set engine and the two connecting rods taking hold of one driving-wheel on each side.







THOMAS CRADDOCK'S PATENT UNIVERSAL CONDENSING ENGINE.

As applied in locomotive purposes. In this arrangement the parallel cylinders are shown with the connecting rods taking hold of two driving wheels on each side.

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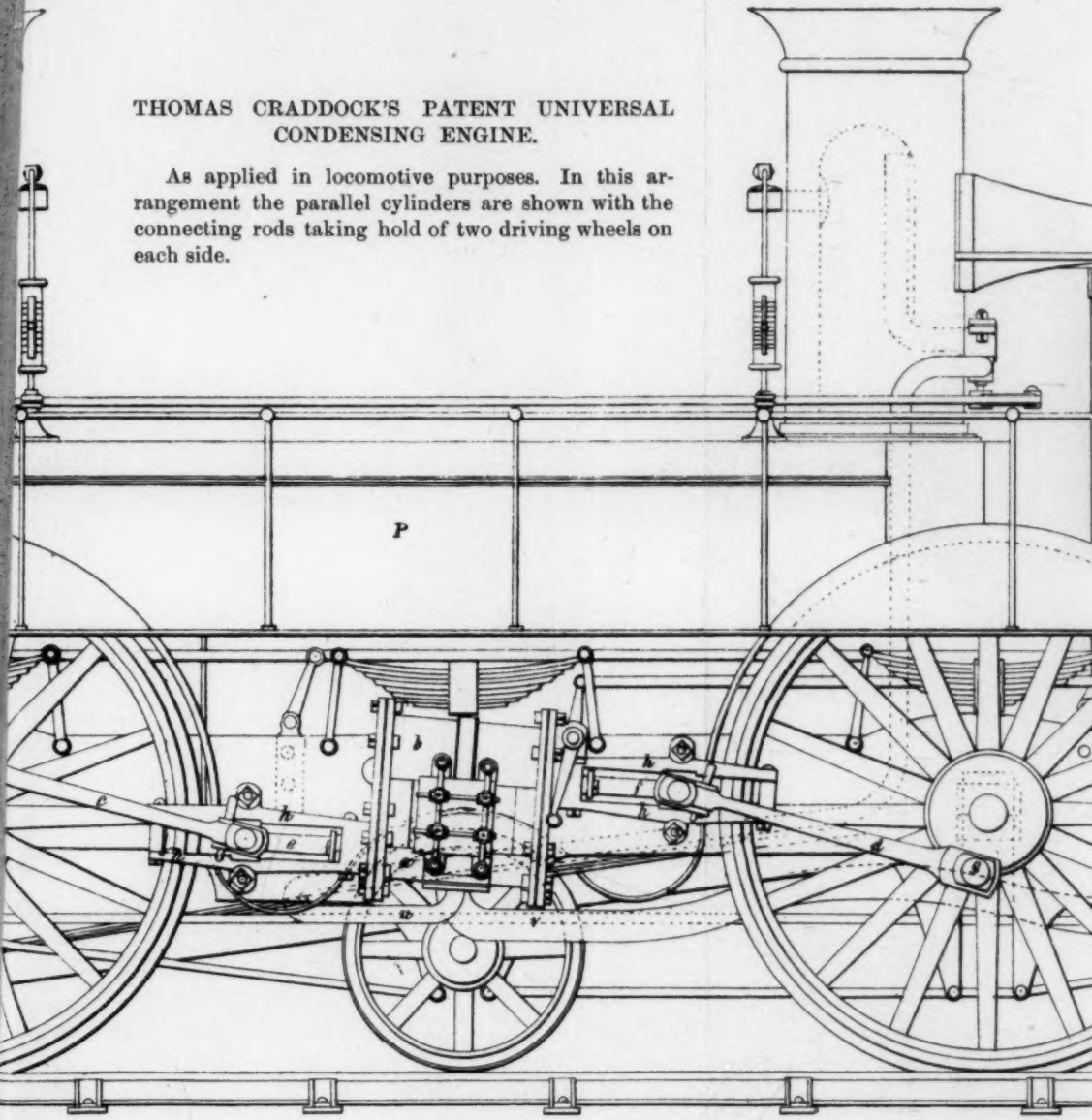

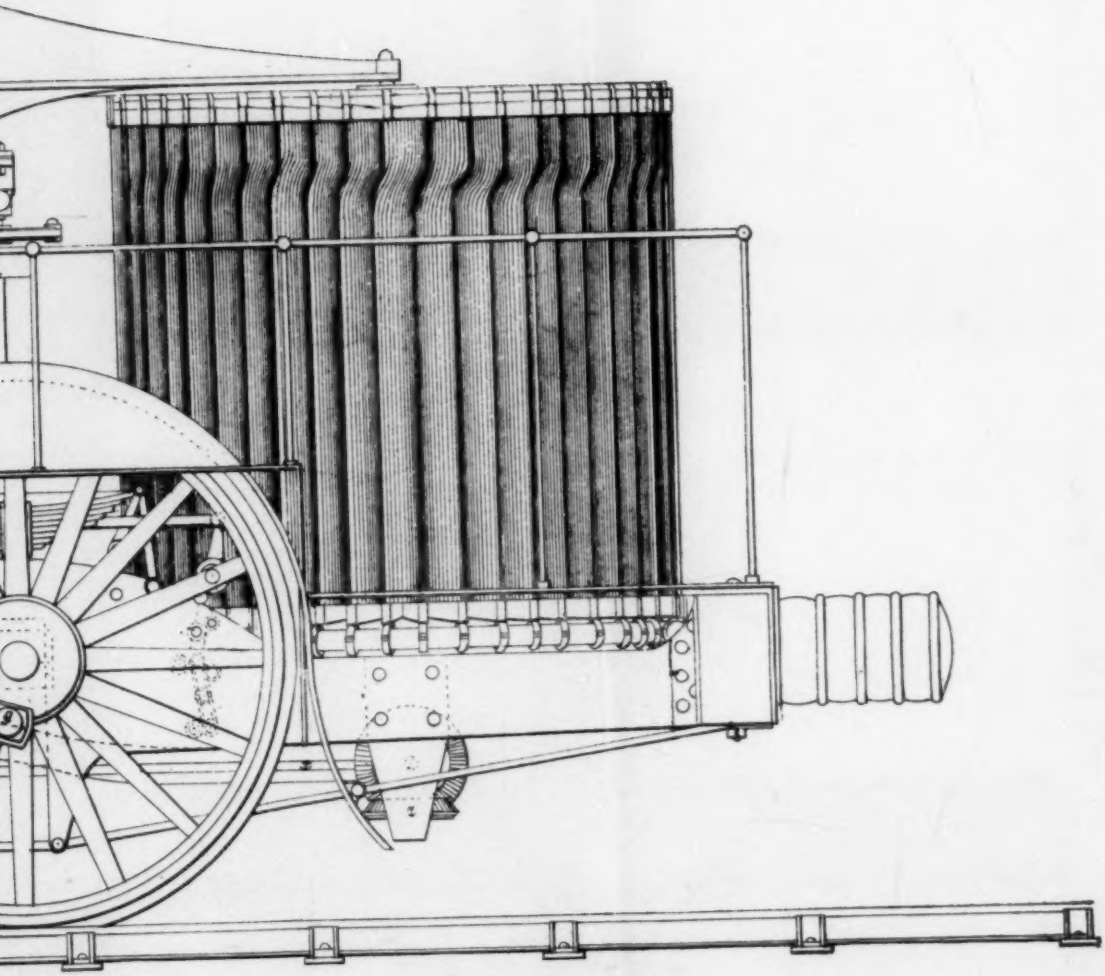

cylinder, and then expanded into a second and larger cylinder, the setting of the cylinders at an angle and connecting them to one crank pin, whether combined or not combined with my other improvements, all or any of them, and in whatever position the said cylinders may be fixed in other respects, as horizontally, vertically or obliquely."

Mr. Craddock's book, published in London in 1847, giving full descriptions of his engines, is illustrated by ten large folding plates of general and detailed views, well and handsomely executed. Three of these plates represent railway locomotives, with two cylinders, a high- and a low-pressure on each side of each engine. In one of them, with parallel-located cylinders, each cylinder is connected to a crank of its own—two to a forward and two to a backward driving axle; in the other, both cylinders on each side, angularly set, so that the axis of each passes through the centre of the driving axle, connect to one crank and to one driving axle; the former having four driving wheels and the latter two, no side rods on either. Illustrations of both these types of construction are given herewith, which sufficiently explain themselves.

Mr. Craddock says: "I ask the reader carefully to note how every principle, which is desirable for economy both in fuel and boiler is embodied in the locomotive represented in the drawing. There we have great extent of grate, low state of combustion, great extent of surface, water free from deposit, the blast not required, the atmosphere removed from the exhaust side of the piston, safety from explosion, every facility for raising the pressure higher at which the steam is generated, a less tendency to priming, every facility for carrying out the expansion principle, the tender dispensed with, the engine of less weight, no steam blowing away at the safety valve, supplies of water not required further than a few gallons per day to make up for leakage. In short, here is every principle requisite to the most perfect, the most economical engine. Never did more sound principles combine to invite a fair trial of any machine than this invention exhibits."

Mr. Craddock proposed to produce steam without blast, by increasing the grate surface to make up for this loss, he would thus secure a quiet running and clean engine. He condensed all the exhaust steam in an enclosed air fan wheel, returning all the water of condensation back to the boiler for reconversion into steam. He used tubular boilers, which afford thin metal, with large extent of surface, supplied pure water to the boiler and thus avoided "deposit," condensed the steam, thus availing himself of the benefit of expansion at the *best* end of it.

The locomotive cylinders have a diameter ratio of 4 : 10 with stroke of 12; driver diameter of 52 and gauge of rails 55½. (No scale on drawings.)

Mr. Craddock certainly conceived many happy engine thoughts, and published much data having creditable simplicity, well worth our study. His theories and principles of construction are well marked with many lines of perfection, and considering date and conditions, his eight years and more of daily experimentation, fraught as they are with results, deserve well of our praise.

Mr. F. W. Crohn, in *Proc. Inst. M. E.*, London, 1879, p. 357, said the "continuous expansion" system was the invention of Mr. John Nicholson (in the year 1850, the same as Samuel's, referred to later on), and engines on that principle were to this day made in considerable numbers at the Blackwall Iron Works for marine purposes.

These engines have been much simplified; they have no receiver and have but one valve to each cylinder, the steam going direct from the high-pressure cylinder into the valve chest of the low-pressure.

The first locomotive built on this system showed an economy of twenty per cent. of coke over ordinary engines, when cutting off at one-third, the work performed being equal in each case, the cylinders were 15 and 17½ inches diameter, giving a ratio of 1 : 1·36 of area.

Mr. James Samuel's patent bears date April 5, 1850, in which claim 8th describes steam engines adapted for economizing steam and fuel. "Their cranks are placed at right angles with each other or nearly so, and with two or more cylinders. A portion of the steam admitted into the first cylinder is caused to pass into the second, and if more cylinders be used, the steam is passed in both cylinders in succession.

9th. "A hollow slide-valve with metallic packing and springs, to allow steam from the exhaust to pass through the back of the valve." For details, of which see *Mech. Mag.* for 1850, p. 403, London.

Extracts from a paper, by Mr. James Samuel, of London, *on a continuous expansion steam engine*, from Proceedings of the *Institution of Mechanical Engineers*, Birmingham, England, January 28, 1852:

"The economy of working steam expansively is well known, but the application of the expansion principle is practicable only to a limited extent in most forms of engine, from practical difficulties in their mode of working, which prevent the attainment of the full economy of which the expansive principle is capable."

"In the locomotive engine there are practical difficulties in carrying out the expansion principle efficiently, beyond a moderate extent, in a single cylinder, from the shortness of stroke and rapidity of reciprocation and the construction of the valve motion; but the ultimate extent to which it could be carried would be limited by the maintenance of the blast, which requires that the jets of steam discharged from the cylinder into the blast pipe should not be reduced below a certain pressure at the moment of discharge. Otherwise, the limit to which expansion might be carried would be the resistance of the atmosphere to the discharge of the steam, added to the friction of the engine, say about ten pounds per inch above the atmosphere."

"The steam is cut off usually by the link motion at from one-third to two-thirds of the stroke, and the steam is consequently discharged into the blast pipe at about from thirty to sixty pounds pressure above the atmosphere, supposing it to be supplied to the cylinders at 100 pounds per inch above the atmosphere."

"It appears that the lower of these pressures is sufficient, or more than sufficient, for the purposes of the blast, to maintain fully the evaporative

power of the boiler under general circumstances, and that a portion of the steam discharged can be spared from the blast to be subjected to a greater extent of expansion."

"In the continuous expansion engine, the subject of the present paper, the steam from the boiler is supplied only to one cylinder; a portion of it is expanded into the second cylinder, which is of proportionately larger area, so as to equalize the total moving power of the two cylinders; and it is there further expanded down to the fullest useful extent, and then discharged into the atmosphere, the portion of steam remaining in the first cylinder being discharged as a blast at nearly the same pressure as the ordinary engines. The economy, therefore, consists in obtaining from such portion of the steam as can be spared from the blast, the additional power of expansion remaining in it, which is thrown away in the ordinary engine."

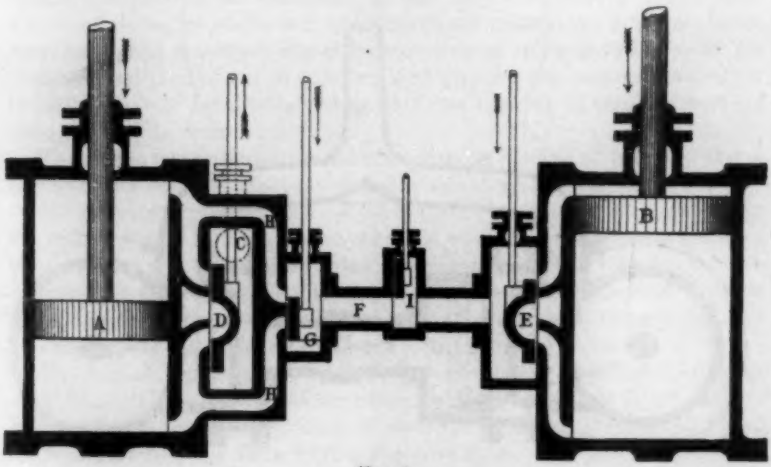

FIG. 4.

Figs. 4 and 5 show the continuous expansion engine as applied to a locomotive. *A* in the first cylinder into which the steam is admitted from the steam pipe. *C*, by a valve *D*, in the same manner as in the ordinary engines. The steam is cut off at half-stroke, and a communication is then opened with the second cylinder *B*, through the passages *H* and *F*, by the opening of the slide valve *G*. The second cylinder *B*, is about double the area of the first cylinder, and the same length of stroke, but the cranks are set at right angles, as in ordinary locomotives; consequently, at the moment of the steam being passed into the second cylinder from the first, the piston of the second cylinder is at the commencement of its stroke."

The steam continues expanding in the two cylinders until the first piston *A* has nearly completed its stroke, when the valve *G* shuts off the communication between the two cylinders, and the valve *D* opens the

exhaust port, and communicates with the blast-pipe *L*, discharging the steam remaining in the cylinder *A*, to form the blast in the ordinary manner. The second piston *B* has then arrived nearly at half-stroke, and contains nearly one-half of the total quantity of steam originally admitted to the first cylinder. This steam is further expanded to the end of the stroke, and then discharged into the blast pipe *L* by the valve *E*, opening the exhaust port.

The return stroke of both pistons is exactly similar to the foregoing, so that about one-half cylinder full of high-pressure steam (or such other portion as may be desired), is supplied to the first cylinder at each stroke, and between one-half and two-thirds of that steam is discharged at the pressure required to produce the blast, and the remainder of the steam is expanded down in the second cylinder, so as to give out all the available power remaining in it.

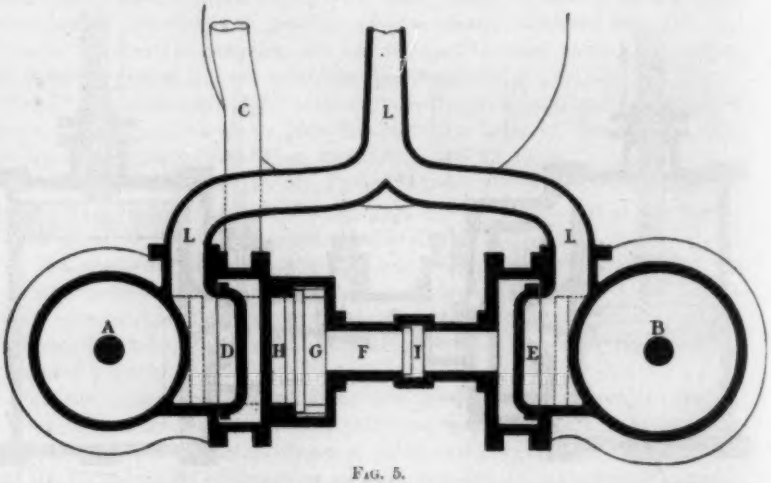

Fig. 5.

For the purpose of enabling the engine to exert an increased power, if required, at the time of starting a train or otherwise, the slide valve *I* is inserted in the centre passage *F* to close the communication between the two cylinders for a short time when required, and the steam from the boiler is then admitted by a pipe and cock into the steam chest of the second cylinder *B*, which is then worked independently of the other cylinder, like an ordinary engine.

"The comparative quantity of steam or of coke required to perform the same work in the several engines, under the circumstances stated above, is given by calculation as follows:

Continuous expansion engine,			100
Ordinary engine cutting off at,	½	stroke,	120
" " "	⅓	"	154
" " "	¼	"	185
" " "	⅛	"	220

"These figures represent the relative economy in the employment of the steam in the several engines; consequently, the ordinary engine, with the best degree of expansion, or cutting off the steam at one-third of the stroke, consumes twenty per cent. more coke than the continuous expansion engine, to do the same work, and from fifty-four to eighty-five per cent. more coke with the more usual degrees of expansion; and an engine cutting off the steam at only one-eighth of the stroke from the termination, as many engines were formerly made, would consume 120 per cent. more coke to do the same work."

"This plan has been tried upon two locomotives with satisfactory results, and the blast was found to be quite satisfactory, when working the regular passenger and goods trains at full speed.

"One of the engines tried was a goods engine of the largest size, on the Eastern Counties Railway; the valves only were altered, and the second cylinder was not enlarged. It was only a temporary experiment, which, of course, caused a reduction in the extreme power that the engine could exert and the object was more particularly to see how the principle could be best carried out in practice, and whether the proposed reduction in the blast could be effected; the result was a saving of twelve pounds of coke per mile in consumption."

The steam was only supplied to one cylinder instead of two, and therefore so much less consumption of steam would take place.

Mr. Samuel explained that the engine did the same usual work during the trial as before; the engine driver could work the engine in the ordinary manner up the inclines by shutting the communication between the two cylinders, or the engine could not probably have taken the load through the trip, but he might be using more steam than usual in the one cylinder by keeping the regulator more open.

Mr. Samuel further said: That in the two engines that had been tried, no difficulty appeared in making steam, and they were not found short of steam. Goods engines working at slow speed might, perhaps, be found the most useful cases for applying the principle. The other engine that had been tried was a passenger engine, in which the second cylinder was made double the area of the first; and it was never found short of steam, though running an express train of considerable weight. * * * The only definite result obtained was with respect to the sufficiency of the blast, which proved quite satisfactory during the regular passenger train work of about a month.

It was remarked there was one novel circumstance in the arrangement of the proposed engine, which did not appear correct in theory; in all the previous double-cylinder engines, the first piston was allowed to complete its stroke before the steam was expanded into the second cylinder, but in this engine the steam is passed into the second cylinder at the middle of the stroke of the first piston, thereby taking the steam away at the very moment that it is most efficient in the small cylinder.

Mr. Samuel explained that at the half-stroke of the first piston the second piston was at its dead point, and began to move very slowly when

the communication was opened between the two cylinders, and consequently took very little steam, whilst the first piston moved through the greater portion of its remaining stroke; but then, as the first piston was getting less effective and approached its dead point, the second piston came gradually into full action, making a *continuous* expansive action, which was the peculiar feature of this engine, instead of the *intermittent* expansion of the other double-cylinder engines.

This was borne out by the diagram taken; showing a nearly continuous line of expansion from beginning to end of the stroke; and the great uniformity in the total moving power of the two cylinders was shown in diagram also.

For these and other details, see original articles in *Mechanics Magazine*, London, 1850, and the paper quoted above.

Mr. D. K. Clark says that, judging from the results obtained, the capabilities of Mr. Samuel's system of working steam expansively were superior to those of any other that had fallen under his observation.

(*B*) DATA RESPECTING ENGLISH, FRENCH AND UNITED STATES PATENTS, WITH PARTICULAR REFERENCE TO SUCH DEVICES AS RELATE TO THE SUBJECT OF THIS REPORT, ARRANGED CHRONOLOGICALLY.

The foundations of the compound locomotive engine were laid in the year 1776, by Mr. Jonathan Hornblower, who invented and built a steam engine in that year and patented the same in 1781. In this engine the steam, after working in the first cylinder, was exhausted into the second one, which was made larger than the first, thus permitting additional expansion of the steam. In this engine the pistons of both cylinders were connected to one working beam, and, therefore, both pistons moved in the same direction at the same time.

In the year 1838, Mr. E. A. Cowper employed a compound engine, the two cylinders of which were connected by a "receiver" and the pistons were connected to two cranks at right angles to each other. Many experiments were made for determining the proper size of the receiver and the losses of heat by radiation and otherwise.

The direct application of compound steam cylinders to locomotives is clearly and elaborately shown by Mr. Thomas Craddock, and patented by him in the year 1846, but we are not aware that his engines were put upon the road, and for this reason the honor of first inventing and also running a compound locomotive belongs to Mr. John Nicholson (a "driver"). This type of engine was further improved and patented by Mr. James Samuel in the year 1850.

The English patent of Frazer Selby, September 9, 1862, shows annular cylinders proportioned in area, 1 : 4½; also two cylinders side by side of same proportion. There is no provision for starting or of equalizing the total pressure in the two cylinders. His drawings are well proportioned and admirably worked out in detail.

"About the year 1870 the Remingtons, at their works in Ilion, N. Y., built a compound steam car for the Worcester and Shrewsbury Railroad Company for suburban traffic. Two cylinders were used with means of supplying boiler steam to the larger cylinder as occasion required. This engine gave good satisfaction until its withdrawal from service a few years ago." These facts are stated by Mr. W. F. Dixon, of Paterson, N. J., in *Trans. Soc. A. S. M. E.* This is Mr. Wm. Baxter's engine, in which a special slide valve, located in the high-pressure steam chest, was used (under control of the engineer), for admitting boiler steam to the low-pressure cylinder and at the same time permit the exhaust of the high-pressure cylinder to escape into the chimney.

The United States patent of Wm. S. Hudson, dated March 11, 1873, claims:

(1) A superheating vessel, located in the smoke-box.

(2) The arrangement of the smoke-box superheater with connections to the two steam cylinders, such, that live steam from the boiler shall

enter one cylinder and be exhausted therefrom into the other cylinder through the said superheater.

(3) A locomotive having a secondary live steam pipe (provided with a controlling valve which may be operated from the foot board) leading to the second cylinder in combination with the main steam pipe leading to the other cylinder arranged for joint operation, relatively to the boiler.

When the controlling valve in the secondary live steam pipe is closed, boiler steam is admitted only to the small cylinder.

The exhaust from the small cylinder is only through the superheater into the steam chest of the larger cylinder.

This invention provides for no independent exhaust pipe to the atmosphere from the small cylinder. It exhausts only into the steam chest of the larger cylinder, so that if this cylinder were disabled, there would be no means of exhausting from the small cylinder, except through the larger by removing its slide valve.

If live steam be permitted to flow without control into the steam chest of the larger cylinder through the secondary live steam pipe, according to the third claim of this invention, this steam chest being in free communication with the exhaust pipe of the smaller cylinder, there will result a back pressure in the smaller cylinder by reason of boiler steam filling its exhaust pipe.

The consequence of this will be the larger cylinder will do more work than intended, and the small cylinder will do little or no work at all.

There is no hint or suggestion of a means whereby the engineer may know definitely the quantity or the effect of the steam he has admitted to the larger cylinder, and no automatic devices for properly taking care of it.

The English patent of John N. Coxon, June 24, 1874, shows cylinders and valves only. It admits steam to low-pressure cylinder directly from boiler. Exhausts from high-pressure cylinder directly to atmosphere. He claims a hollow valve to permit exhaust from high-pressure cylinder directly through the same to the steam chest of the low-pressure cylinder, same as was done by Samuels in 1850. No equalizing of pressure on the two pistons is mentioned.

The French patent of A. M. Mallet, October 10, 1874, shows a compound locomotive with two tandem cylinders, placed in centre of locomotive under the smoke box.

It is provided with a slide valve, whose chest is outside of the smoke-box, with stem extended to the cab under control of the engineer.

This slide valve, *in one position*, will permit boiler steam to enter the low-pressure cylinder, when the exhaust from the high-pressure cylinder is escaping to the atmosphere, while at the same time boiler steam is entering the high-pressure cylinder as usual when the throttle is open.

In *the other position* no boiler steam can enter the low-pressure cylinder, but the high-pressure exhaust is closed to the smoke-box, and is directed to the low-pressure cylinder, while this cylinder exhausts directly into the atmosphere.

A small spring loaded valve is attached to the steam way to the low-pressure cylinder (in sight of the engineer), so that when it blows off he can regulate the admission of boiler steam to the low-pressure steam chest. This valve is loaded to a pressure of equal to four-tenths or five-tenths the normal boiler pressure.

The English patent of Henry P. Holt, November 6, 1876, uses an automatic intercepting valve between low-pressure steam chest and the receiver. No mention is made of reducing valve to equalize the total pressures in the two cylinders.

The French patent of Alexander Arson, of Paris, May 13, 1878, is a two-cylinder compound engine, having a slide valve, worked by an eccentric which is operated by hand for regulating the flow of live steam into the steam chest of the low-pressure cylinder for starting.

The English patent of Thomas Robertson, January 1, 1881, is for a two-cylinder compound provided with means of injecting a jet of boiler steam into the low-pressure cylinder. No mention of steam reducing valve.

The United States patent of Henry D. Dunbar (a four-cylinder tandem compound locomotive), dated April 24, 1883, is provided with an independent *D* slide valve (on three ports) moved by the engineer in the cab, to admit boiler steam to the low-pressure cylinder, and permit the high-pressure cylinder to exhaust into the atmosphere at the same time. This was done precisely in the same manner by Mr. Baxter in 1870. No mention is made of an equalizing pressure valve for the low-pressure cylinder.

The English patent of Edwin Foden for a compound traction engine, July 23, 1885, claims:

"In compound engines, having either one or more high-pressure steam cylinders in combination with one or more low-pressure steam cylinders, the use of a three-way cock, or its equivalent, for the purpose of temporarily suspending the compound action of the high-pressure steam cylinder and the low-pressure cylinder, so as to cause each cylinder to receive its steam direct from the boiler, and to exhaust its own steam direct into the atmosphere, or independently, so that the low-pressure cylinder, does not then take the exhaust steam from the high-pressure steam cylinder, but becomes for the time being an additional high-pressure steam cylinder."

Mr. Foden's drawings do not show a reducing or relief valve, nor does he lay claim to such a device; but he prefers to provide the steam box of the low-pressure cylinder with one to reduce the pressure within.

The English patent of Richard C. Parsons, August 3, 1886, provides a valve which opens the high-pressure exhaust to the atmosphere. This valve is normally held close by a spring, but is opened by steam upon a piston connected with the valve, which piston is controlled by the engineer by means of a pipe and a cock.

Another drawing shows a second valve which admits live steam to the low-pressure cylinder and at the same time opens high pressure exhaust to the air. There is no mention of an equalizing pressure valve.

The English patent of Wm. Hornsby and Fred. J. Cribb, November 25, 1886, exhibits a slide valve, operated both ways only by the engineer from the cab, for admitting live steam to both high-pressure and low-pressure cylinders and opening the exhaust of the high-pressure cylinder to the atmosphere when starting.

The United States patent of Thomas W. Worsdell, dated April 5, 1887, following his English and French patents, says: "One of the cylinders takes steam direct from the boiler. When this steam is exhausted it passes through a superheating pipe to the low-pressure cylinder. After performing its function therein, the steam from the low-pressure cylinder is exhausted direct up the chimney."

"To render the engine efficient in starting, a starting valve is provided by which steam can be conveyed direct from the boiler to the low-pressure cylinder, and in order to prevent such steam filling the exhaust steam pipe of the high-pressure cylinder, and consequently the high-pressure cylinder itself there is provided a valve that I call the 'intercepting valve.' When closed this intercepting-valve will prevent the live steam getting back to the high-pressure piston. A flap-valve is preferred as it can be closed at will, and will always be thrown open by the steam itself when exhausting commences from the high-pressure cylinder. The starting-valve may be arranged to be opened by hand against a spring, so as when liberated to be closed in an automatic manner. The low-pressure cylinder is fitted with a relief valve at each end, to prevent the cylinder being charged at too high a pressure when steam is admitted direct from the boiler through the starting-valve."

No means are provided for running this engine continuously as a simple one, and no device shown or described for proportionally reducing the live steam pressure in the low-pressure cylinder.

The United States patent of August Von Borries, dated April 19, 1887, after seven foreign patents for the same invention, has for its object the construction of a two-cylinder compound locomotive, such that the connection between the cylinders can be cut off and both be worked at high-pressure when desired. An automatic valve is used for intercepting the high-pressure cylinder exhaust pipe and in the same movement of this valve, when it closes, a small live steam opening is made into the low-pressure cylinder steam chest. The moment this valve opens, by accumulated pressure in the high-pressure cylinder exhaust pipe, the live steam openings are closed and the engine goes at once into compound working.

There is no provision for continued simple running and no means for equalizing steam-pressure upon the two pistons.

The English patent of Halpin and Timmins, July 14, 1888, claims: "In a two-cylinder compound locomotive; a starting valve, consisting of a double seat valve loaded directly by a coil spring and allowing (on the engine being started), high-pressure steam from the boiler to pass directly into the low-pressure cylinder, until the back-pressure of the steam in the receiver and that of the spring, which act on the top area of the valve,

exceed the pressure of the boiler steam, acting on the lesser area of the underside of the valve, in consequence of which the said valve drops back on its seat and then the engine works compound."

In Robert Lindner's United States patent, May 28, 1889, the remark is made, that: "It is necessary, in locomotives in starting the engine that steam of a reduced pressure direct from the boiler be admitted to the low-pressure cylinder, in order that the low-pressure cylinder should start the engine."

To accomplish this result, he provides a cock in a small branch pipe for admitting boiler steam to the high-pressure cylinder exhaust pipe, connecting the lever of this cock to the reverse lever and constructing the cock so that it shall admit steam only at the extremes of its stroke. He also forms small vent holes on the inner lips of the high-pressure cylinder slide valve, which in the middle of its travel, relieves the high-pressure piston from unequal strain, by opening both ends of the cylinder to the exhaust pipe for a moment, while the valve is passing. No device is mentioned for equalizing the steam pressure in both cylinders other than by wiredrawing it into the low-pressure cylinder.

The United States patent of J. Lewis, dated June 11, 1889, consists of four parallel cylinders, under the smoke-box, the steam to all of them is controlled by one rotating elastic valve, centrally located. One high-pressure and low-pressure cylinder on each side of locomotive is connected to one cross-head, with one connecting-rod to the crank.

One valve, controlled by engineer, for admitting boiler steam to both low-pressure cylinders at starting.

No mention is made of independent exhaust for the high-pressure cylinders at starting, and no allusion to, nor provisions for, equalizing the pressure of steam upon the pistons, when live steam is used in low-pressure cylinders.

The elastic valve will permit unequal compressions in the cylinders to escape.

The power of the high-pressure cylinder is necessarily weakened when live steam is admitted to the low-pressure steam chest.

The United States patent of Richard H. Lapage, dated July 8, 1890, following his English patent is for a three-cylinder compound locomotive, in which, however, the *two* low-pressure cylinders act as one, being connected to one cross-head and receiving the exhaust steam in the usual way from the one high-pressure cylinder.

The only object of duplicating the low-pressure cylinder is, the specification says, to avoid the danger of "fouling the loading gauge, existing platforms, tunnels, and the like." "By this means the use of a large overhanging low-pressure cylinder is obviated." About this, we have proven, there is no real concern, as there is room, by proper designing, for any *required* single low-pressure cylinder.

In this engine there is no independent exhaust way to the atmosphere for the high-pressure cylinder; no means of continuous single running and no suggestion even of devices for equalizing the steam pressures in the high- and low-pressure cylinders.

The United States patent of Albert J. Pitkin, dated April 14, 1891, covers an intercepting valve operated by "live steam to close it and shut by pressure of the steam in the low-pressure cylinder."

9th claim: "A valve controlling the admission of live steam to the low-pressure cylinder and automatic mechanism for positively opening said valve;" that is, it is actuated by the intercepting valve.

No mention is made of, nor drawings show, an automatic pressure-equalizing valve.

The United States patent of Francis W. Dean, September 22, 1891, covers an automatic intercepting valve working vertically.

"The construction insures the opening of the converting valve before the pressure of exhaust steam in the high-pressure exhaust passage accumulates above the receiver-pressure and thus relieves the high-pressure piston of the early back-pressure."

"The intercepting valve opens in advance of an accumulated back-pressure on the high-pressure cylinder to any desired degree."

No mention is made or drawing to show an automatic pressure reducing valve for low-pressure cylinder.

This patent proposes to admit live steam to the low-pressure cylinder at the same time live steam is admitted to the high-pressure cylinder to facilitate starting. This is done through the intervention of an intercepting valve and a converting valve, both of which are vertically opened and shut.

When boiler steam is admitted to the receiver by which to run the low-pressure cylinder as a simple engine, the intercepting valve closes, so as to prevent this steam from filling the exhaust pipe of the high-pressure cylinder which would reduce or destroy its power.

There is no separate exhaust pipe to the atmosphere shown or described, for the high-pressure cylinder.

There is not a word said about the necessity of, nor a contrivance for equalizing the total pressures of steam upon the two pistons, when both are working as simple engines.

(C) NOTES, DATA AND REFERENCES BEARING UPON AND RELATING TO THE USE OF STEAM IN COMPOUND LOCOMOTIVES AND OTHER STEAM ENGINES.

In the preparation of this report, your committee has extended its searches and has presented a wider range of subjects than is usual in such cases.

This procedure is desirable in view of the increasing interest taken in the compound system of locomotive construction.

The advisability of detailing the means which have been employed to adapt the two-cylinder compound steam engine to the popular two-cylinder type of locomotive, has been considered to be right and proper in this connection since this type out-numbers all others.

Experience with locomotives, everywhere, has shown the advantages of simplicity of construction in all the working parts; this committee, therefore, has dwelt at considerable length upon such details and methods, as

have contributed to economy, without increasing the number of parts used for transmitting the power of the steam to the driving wheels.

The volume of railroad service having grown to such unprecedented magnitude, we feel that whoever contributes to it, or reduces the cost of its maintenance, confers a lasting benefit upon mankind.

There is no claim made by Mr. Batchellor for a two-cylinder compound locomotive by itself considered.

It is well known that the first two-cylinder compound engine was invented and built in England by Jonathan Hornblower, in the year 1776, and was patented by him in 1781, as stated above.

It is also on record that one John Nicholson, an English "engine driver," devised and run a two-cylinder compound locomotive on an English railway in the year 1850, since which time numerous patents have been granted for two-cylinder compound engines adapted to stationary and locomotive use, and with attachments for various purposes. These attachments differ according to the conception of their inventors, and the service to be rendered by their inventions.

The question of the objectionable width of two-cylinder compounds, due to the increased diameter of low-pressure cylinder is answered by the fact that numerous engines of this type are now running in this country and abroad. Builders of engines are now making two-cylinder compounds, even of the heaviest type, and officers of several of our roads who are responsible for their performance are having them made.

As to clearance width of locomotive, from the *Locomotive Engineer*, for November, 1891, p. 206, we take the following:

"The question of the application of the two-cylinder compound locomotive, such as used in heavy service for both passenger and freight traffic, is answered by the Schenectady Locomotive Works' people, who have already built a number of the two-cylinder type, and have designed a heavy compound consolidation engine of equal capacity to the 22 x 28 inch cylinders on the Union Pacific, which are believed to be the largest and most powerful locomotives at work in regular road service at the present day.

"The low-pressure cylinder is thirty-two-inch diameter, yet the extreme distance outside of cylinder does not exceed that of other two-cylinder compounds now running.

"The design demonstrates the fact that the popular two-cylinder type of compounding can be applied to the heaviest locomotive in road service at the present time."

We have found on inquiry, that every superintendent of motive-power, or master mechanic in this country, who recently has built a compound engine, or rebuilt a simple engine by changing to compound, has in every case used the two-cylinder type.

So for example, Mr. Lander, of the old Colony, and Mr. Mitchell, of the Lehigh Valley, each is building a Dean. Mr. Stevens, of the Lake Shore, has had the Brooks Locomotive Works to build a two-cylinder engine; the C. B. & Q. has built one, and are now building two more of

this two-cylinder type. In addition to these the Southern Pacific and the Atchison, Topeka and Santa Fé have done the same.

If there was any serious objection to this type of engine, due to its greater breadth, it is fair to believe these men would not order them built.

The Rhode Island Locomotive Works say: "In regard to the clearance width of the two-cylinder type of compounds there is no trouble whatever in going as high as a thirty-one inch diameter for the low-pressure cylinder, which is equal to about two and one-half times the area of the twenty-inch high-pressure cylinder. This proportion we consider is near right as it is possible to get, and we think that by taking a little pains in the designing, we could get even a larger cylinder than thirty-one inches, but have had no reason to look into the matter any further than this, as the twenty-inch cylinder for the high pressure is as large as anything that we have built on our largest consolidation engines, so that we do not think there is any ground for complaint on this score."

A contributor to the *Railroad Gazette*, for August 21, 1891, p. 575, says of two-cylinder compounds, in answer to the main objection, that "the cylinder ratio could not be made large enough, and room still be found for the cylinders within the permissible width of the locomotive." He not only proposes to offset the centre of the low-pressure cylinder to a point within the centre of its application on the crank pin, which, however, is proven unnecessary by references to replies given herein, but further asks, why not increase the diameter of the high-pressure cylinder and expand the steam more in that which would also help the engine in starting?"

"It is being generally conceded that the difficulty with the two-cylinder engine (he refers to certain existing types) is that after the first exhaust of the high-pressure cylinder, when it should be exerting a comparatively high-pressure on the crank pin, it is not doing so, because of the back pressure in the receiver, and when working compound the two-cylinder locomotive has not as much average total pressure on the piston as the simple engine which it was built to replace."

"This has resulted from following an empirical rule; that is, to make the high-pressure cylinder *one inch larger in diameter* than the cylinder of the simple engine of equal power; this is wrong."

"The two cylinder is really the simplest and most desirable type of compound locomotive."

Mr. Thomas Urquhart, *Proc. Inst. M. E.*, London, 1890, p. 60, says: "The results of the author's experience are such as to leave no doubt in his own mind that compound locomotives are the engines of the future in all countries. "What is really wanted, is to mature a thoroughly efficient *two-cylinder compound with moving parts as light as possible, and well balanced.*"

It is not worth while to consider the objection to weakened draft in the chimney by reason of diminished exhaust pressure and reduced number of exhausts, because all the compounds are running satisfactorily, with good steaming qualities.

In Mr. W. Fletcher's work on *Steam Locomotion on Common Roads*,

London, 1891, we find the following in reference to the Messrs. Fowler's recent type of compound road locomotive: "By the use of a low-pressure cylinder working in conjunction with a high-pressure cylinder, the greatest possible amount of expansion is obtained, and almost all the power in the steam is used before it is discharged into the atmosphere, the pressure of the exhaust steam being only eight pounds, which is just sufficient to create a draught necessary for the combustion of the fuel.

"These engines will do the same amount of work with thirty per cent. less fuel and water than the ordinary engines in every-day use. In consequence of the steam passing from these engines into the atmosphere at the low-pressure of eight pounds, the noise caused by the exhaust and all dangers from sparks are avoided." The road locomotives of other builders in England have performed equally as well.

We have all been taught by long existing practice to believe that a locomotive boiler will not make steam enough for the needs of the engine, without blowing all the exhaust steam from both cylinders at high-pressure tension into the stack, and that any reduction of its strength would materially lessen the generation of steam. See Samuel's continuous expansion engine for proof of the existence of this belief prior to the year 1852, where part of the high-pressure exhaust steam and all from the low-pressure cylinder went for blast.

From Mr. J. Samuel's supplementary paper on his continuous expansion steam engine, we quote:

"As far as they went, however, they showed that the blast could be reduced without impairing the efficiency of the engine. In a goods engine of the largest size, on the Eastern counties, the valves were altered, but the cylinders were retained both of the same size, and the result was a saving of twelve pounds of coke per mile. In a passenger engine, the low-pressure cylinder was made double the area of the high-pressure one, and it was never found short of steam, though running with express trains of considerable weight for a month's regular work."

In M. Mallet's two-cylinder compounds, three of which were in service prior to May, 1878, employed on local traffic and at times running twenty-five miles per hour. "The draught was ample, so that the boilers in spite of small dimensions supplied the wants of the engine abundantly."

From the above statements, it would appear useless to consider this objection, because all the engines fitted with low-pressure blast are now running satisfactorily in this particular, and we may safely add the remark here that, as the Rhode Island compound can be run as a simple engine, at any time and for any length of time as a simple engine, with the full blast efficiency, due to simple running, there need not be any lack of rapid steam generation for want of known means for doing it.

Furthermore, there is less steam to be made if compounding saves some of it, and in any case, *all that is made goes through the stack.*

To answer the question as to the value of superheating the exhaust steam on its way to the low-pressure cylinder as patented by Hudson, reference is made to the results of experiments, conducted by the C. B. & Q.

R. R. Co., who concluded that the cost of maintenance was more than the advantages gained.

This has nothing to do, however, with extending the pipes through the smoke-box, which is the most direct course, has many constructive advantages and keeps them in a closed chamber heated to from 400° to 1,000° of temperature, which is, perhaps, the cheapest method of clothing them.

Mr. T. Moy (in *London Mech. Mag.*, for August, 1863), proposes to increase the efficiency of the heating surface of steam boilers, "by increasing the *surface in contact with the water*, without a further increase of the absorbent surface." He further says: "It is pretty generally known that flanges cast on air-warming apparatus, greatly increased the effect of such apparatus, the cause being that a greater surface of heated metal is in contact with the air." His plan is to form flanges on the outsides of the tubes. Whether this will be as effective when the heat is required to pass in a reverse direction, remains to be proven.

Mr. W. F. Dixon, of Paterson, N. J., in vol. xi, of *Trans. Amer. Mech.*, p. 870, on the "Efficiency of Locomotives," says: "The C. B. & Q. R. R. Co. between 1870 and 1874, went fully into the subject of superheating. In these experiments the front tube sheet of the engine was set back into the barrel of the boiler some distance from its normal position. In the space thus left was fitted a separate cylinder, filled with tubes, through which the products of combustion had to pass on their way to the atmosphere. The dry pipe entering this cylinder at the top, and the steam, after circulating among the tubes and becoming superheated in doing so, passed to the cylinders of the engine through pipes connected to the bottom of the superheater.

"The resulting economy was, however, more than offset by the expense of keeping up."

The most conclusive test of the compound locomotive is that which is made in road service by the rank and file of engine men, extending over considerable mileage, under the usual varied conditions of present practice and with conditions precisely alike.

Your committee is satisfied that this method of experiment and comparison has been fairly carried out in the cases before us.

This committee decided that we should make personal inspection of these locomotives; we take pleasure in repeating here the report upon their performance by one of its members:

"I was in New York on the 15th of March, 1892, and went over to Brooklyn to see the two-cylinder compound locomotive running on the Kings County Elevated Railroad. This engine was built by the Rhode Island Locomotive Works, and has been running several months. Went to the General Manager's office where was shown the performance sheets of their engines, and when the engine came along we got on and rode to the Ferry and then back to the terminus of the road (nearly eight miles) and then back again to the Ferry and then again up the steep grade (which is 180 feet per mile), where it acted as a helper for another engine.

"During this whole time the engine performed its duty to the *entire*

satisfaction of everyone, showing no more trouble to operate than a simple engine.

"It *rides well*, and were it not for the *absence* of *noise*, *sparks* and *dust*, one would not know that he was on a compound engine. It is using a nozzle four inches in diameter and steams freely with the door partly open, nearly all of the time.

"There was not a single moment during all of my ride where any of the arrangements that are used to change from simple to compound showed any desire to give trouble, but on the contrary, they all responded promptly. The trip was a very pleasant and satisfactory one."

In estimating the economy of various types of compounds employed on different roads, care must be taken to note all the conditions of running, which may greatly affect the comparative result.

Engines built and used for yard work and suburban traffic which are well nigh all stops and starts, with very short spaces for compounding, must not be paralleled with express engines on long runs, with a clean sweep the whole distance for compound running.

We must beware of incongruous comparisons.

Mr. Angus Sinclair (Sec. Am. Rwy. Master Mechanics Assoc'n) says, in the *Trans. Soc. A. S. M. E.*, in article on the "Efficiency of Locomotives," by W. F. Dixon, 1890, "few engineers would allow themselves to be influenced by results which are not obtained in road service."

Your committee has considered the figures of coal saving from various authorities.

	Per Cent.
The first compound locomotive run in the year 1850 and Samuel's continuous expansion engine of 1852, saved in coke,	20
Fowler's traction engines. English, saved,	30
Foden's " " " "	29 1-10
Burrell's " " " "	30
Worthington's non-condensing steam pump,	30
Worsdell's compound locomotive on English Railroad,	18 to 25

Mr. Urquhart made various numerous experiments with petroleum fuel on five compound locomotives and an equal number of non-compounds during five summer months, which showed a saving in favor of the compounds of from 18·22 to 18·96 per cent. of such fuel. He also gained an economy of repairs on the passenger locomotives, equal to 49·2 per cent., and 28·8 per cent. on goods locomotives.

In reference to the valves used for reducing the pressure of steam when directly employed in the low-pressure cylinders, which are necessary to prevent over-pressure in the same, and equalize the steam action in both cylinders, your committee has not found any other in use that fulfils this important requirement to any noteworthy degree, like that one applied to the compound locomotives built by the Rhode Island Locomotive Works.

Many of the earlier and later methods of preventing an excess of live steam pressure in the low-pressure cylinder are by wire-drawing the steam through small pipes and drilled holes, which are opened and closed by the engineer or by automatic action of other valves, which control also the

exhaust ways. Some prevent over-pressure by spring-loaded snifting, safety relief valves or slide-valves. Wasting the steam in the atmosphere within sight of the engineer, who will know by this escape that the cylinder has overmuch of steam, and can act accordingly.

Whatever kind is used, and the presence and absence of them will be noticed in the detail of the several devices and patents quoted.

Your committee does not believe that the mere suggestion of and use of a pipe with a connected cock or valve for admitting steam to *anywhere*, merits notice of novelty at our hands, nor does a spring loaded safety or relief valve for giving notice of over-pressure or danger claims special attention in an inquiry of this nature.

Your committee is fully persuaded that in the design and construction of a compound locomotive they should be made as simple as possible.

With the adoption of two cylinders the number of working parts will be reduced to a minimum; the steam ways and everything else appertaining to the employment of the steam in the machine will necessarily be the least intricate, and will in turn reduce first cost and maintenance.

Mr. Alexander Borodine states, in *Proc. Inst. M. E.*, London, 1886, p. 353: "Considering that the compound locomotive with which the experiments were carried out, involves scarcely any complication and that it costs about the same to build as the ordinary engines and that a decrease in consumption of fuel lessens the cost of boiler repairs and of providing feed water, etc., it may be concluded that there is an undoubted advantage in building locomotives on the compound system."

Your committee readily assents to this proposition. One of them, more than ten years ago, announced the fact that a compound land engine could be built for same money as the usual high-pressure non-condensing engines then built; the saving in boiler capacity and equipment fully pays for the necessary additions to the engine.

The economy of short steam passages by which "much waste of steam is avoided," and the exposure of "less surface is presented for atmospheric resistance and cooling—a very important consideration at high speeds," are points claimed by Mr. Joseph Lewis in his United States patent of June 11, 1889.

In the English patent (1889) of J. T. A. Mallet, mention is made of his preference for two cylinders "both for simplicity of construction and to avoid an excessive amount of cooling surface."

On the subject of the economy of steam expansion and loss of power by radiation, Mr. Robert Stephenson said "that in the 'Planet,' one of the early locomotives made in 1832, he had the cylinders carefully enclosed inside the smoke-box instead of being outside, and there was found to be a considerable increase of power effected by the plan. That was the first locomotive constructed with heated cylinders, and it appeared the principle ought never to have been deserted." (*Proc. Inst. M. E.*, 1852, p. 85.)

Mr. D. K. Clark found by the indicator diagrams "that a great condensation of the steam took place in exposed outside cylinders during the first part of the stroke, from the coldness of the cylinders, and a consider-

able amount of condensation also was caused even in protected cylinders, where they were not artificially heated by exposure to the hot air in the smoke-box, because the temperature of the mass of the metal in the cylinder remained about the mean temperature of the steam while expanding in the cylinder, which might be many degrees below the original temperature of the steam on entering from the boiler." (*Proc. Inst. M. E.*, 1852, p. 87.)

Mr. Cowper "thought there would not be found to be any loss by condensation in a well-protected cylinder; he had not found any to take place in the experiments that had been tried on expansion."

"With respect to Mr. Samuel's mode, lately patented, of working steam expansively to a degree contemplated at four to six times the initial volume, by exhausting from one cylinder into the other, it is plain that the necessary conditions for the economical employment of such an extent of expansion, demand a much better provision for the preservation of the steam than is to be found in the ordinary arrangements of outside cylinders. According to Mr. Samuel's designs, the cylinders are placed outside in the usual manner, without any expedient for preserving the temperature of the steam; and it is easy to understand that special means must be adopted for this object, to secure an economical promotion of expansive action to the extent peculiarly available by his system."

D. K. Clark, *Railway Machinery*, London, 1855, p. 84.

"Mr. Stephenson mentioned an experiment by Mr. Trevithick, in which he found that *one* bushel of coal burnt under the cylinder did as much duty as *five* bushels of coal burnt under the boiler, showing the economy of keeping the cylinder warm." (*Proc. Inst. M. E.*, 1852, p. 131.)

"The annular cylinder compound engine, worked with one slide valve, was originally proposed in 1837 by William Gilman, and it has for many years been used by a London engineering firm in the construction of engines to drive corn mills. But the writer (Fred. J. Bramwell, of London) believes that care has never been taken to steam-jacket the high-pressure cylinder, which has thus always been bathed in an atmosphere of the low-pressure steam; this the writer looks upon as the cause of considerable loss." (*Proc. Inst. M. E.*, 1872, p. 147.)

To the above observation we may add our own: If there is loss in expanding too far in one cylinder, by which the departing steam lowers the temperature of the cylinder below that of the incoming steam, then, indeed, a high-pressure cylinder entirely surrounded by low-pressure steam must be at a great disadvantage.

Watt's grand invention consisted in condensing in a separate vessel, his aim being to economize by keeping the cylinder "always as hot as the steam that entered it."

The transition of this happy thought to the kindred one of *expanding in a separate vessel* seems not to have been made, although embodied in Hornblower's invention. On this occasion Engineer Blunder sat upon the Wishing-gate.

This subject was earnestly studied and widely published by Craddock

in the year 1840, and later on, who showed clearly the advantage of preventing high-pressure steam from coming in contact with the walls of a vessel from which low-pressure steam was escaping, and who also proved his theory to be true in practice by making a twin-cylinder engine which performed double work with the same amount of steam. As modern compound engine practice has made this matter as familiar to us as office words, we need no labored argument for demonstration of it; we can only wonder why a matter so simple was not taken advantage of long before.

We must understand once for all that expansive working of steam is not a *gain* but a *saving*. The want of a proper understanding of this difference may have been the cause of the diverse views which have been held upon this subject by prominent engineers.

Economy goes with the expansion of steam, and with least steam waste which are secured by proper proportioning of the cylinders to the work to be done, and by efficient clothing of the exposed steam chambers.

There is no reason for useless loss of steam on its way to work, when there are well-known methods of saving it.

Experiments prove that a well felted boiler will save twenty-five per cent. of fuel over an exposed one; even an open door sensibly affects the running of a stationary engine; then why are not locomotive cylinders seriously affected when the storm door is always wide open?

Proofs are already abundant that economy in the use of steam runs in the line of continued expansion in more vessels than one; we were told this just 116 years ago, and we are slow at learning the lesson and putting it in practice.

About the same time Cornish men told us that best clothing meant increased saving of steam.

It has always seemed strange that a weather-chilled railroad man never applies the same reasoning to his exposed steam cylinders that he promptly does to himself, the object being the same in each case—the retaining of heat.

The hydraulic engineer soon finds out that he must avoid sudden contractions and enlargements and sharp turns in the water-ways of his constructions.

All this speaks plainly to the engineer: Save your steam when you have made it against loss due to radiation, and spare it from needless resistances while passing from the generating vessel to the point of application.

Of all things provide that your steam shall act quickly, and this is effected most perfectly by the least number of parts and ways through which it is to flow.

In order that the points of these statements may be clinched, as applied to the subject before us, we repeat Watt's golden rule: "The supreme excellence of machinery is its simplicity." We further quote from one of our best English authorities on steam and on the machines in which it is employed:

"There is a peculiarity in the double-cylinder engine, in its requiring a

pipe or passage of some kind, through which the steam must travel, from one end of the small cylinder to the opposite end of the large one; and this passage should evidently be as small in content as possible, consistently with allowing the free passage of the steam."

"When the communication is opened at the end of the stroke, the steam, passing from the small cylinder, has to expand and fill the passage before it enters the large cylinder; and if the passage be large, the steam must necessarily suffer a reduction of pressure in so doing, which must seriously diminish its effective action on the large piston during the future stroke, and so cause much loss."

"In some engines, the author found this loss so great as to waste nearly half the power of the engine; and even in the best that were examined, such a considerable percentage of loss occurred, as almost to neutralize the expansion altogether."

"Much attention was therefore given to this point in designing the new engines; and it was found essential to the success of the engines that some arrangement of valves should be adopted which should satisfy the following conditions:

(1) That they should be of the simplest possible character and free from liability to derangement.

(2) That they should admit of the steam being cut off from the small cylinder at such a point as might be necessary to secure the required regularity in the motive-power of the engine.

(3) That they should give the clearance spaces the smallest content possible, and in particular, should allow the passage between the two cylinders to be direct and unimpeded, and of no larger capacity than was absolutely necessary for the passage of the steam."

"It was further found conducive to economy that the passage between the two cylinders, should, if possible, be carefully protected from cooling." Wm. Pole, from *Newton's London Journal of Arts*, August, 1863.

The fact is well known to every locomotive engineer that the requirements of a locomotive differ wholly from those of a stationary engine.

The conditions vary continually.

When starting a locomotive its greatest power is needed, this may also be needed to overcome occasional resistances at any time along the roadway. That locomotive, therefore, which is supplied with mechanism, at the will of the engineer, capable of running the engine at full power at any time and for any length of time, and as easily convertible into compound running, must take the precedence over every other.

For elevated railway, rapid transit service, such locomotives as the two-cylinder Rhode Island type is admirably adapted.

Their extreme cleanliness and quietness, easy riding and economy of oil commends them highly for service in cities.

Their economy in the use of fuel and water, combined with the lighter carriage of these requisites, and a more even distribution of the application of their power to this kind of service, which is conducted upon structural highways, possess many advantages.

The ease with which these engines are thrown into simple working, having full pulling power, as becomes necessary at certain times of the day, when the flood-tide of travel is all going one way, and as happens on many roadways, these extra heavy loads must be taken at full speed, up and over long and steep gradients, and when these are passed, a simple turn of the hand will change to compound running.

A compound locomotive, with multiple cylinders, is not built for the sole purpose of getting more power; the chief object to be gained is the saving of steam, which can be done in two cylinders, as commercially well as in any greater number on a locomotive.

In all cases, whether two or more cylinders are used, it is generally understood that in order to secure good results, the cylinders are proportioned to the weight on the driving wheels, and to the pressure of the steam.

We are more concerned here, however, with the appliances by which any type of compound locomotive may be made *universally applicable* to *any* road and to *any* service.

This invention is not simply ingenious, although it takes rank with any having high merit in that particular, but the merit we desire to report favorably upon, and give award to, is of such character as possesses commercial value.

A two-cylinder compound can be put to any simple engine, for less cost than any other type, and in doing so will replace and require the least number of working parts. The altering of existing simple engines into two-cylinder compounds, is thus made altogether feasible, and the building of new ones can be done at a cost very little over simple ones of same type and power.

The Rhode Island Locomotive Works improvements solve these problems perfectly. They furnish a locomotive that, for any time and service is at once simple or compound—an accomplished fact which your committee believes has not been done before in any country.

A great number of two-cylinder compounds, having the Worsdell von Borries type of valves and steam-ways, have been made, and are now running with good economical results.

If, therefore, the two-cylinder type of engine is so well favored, as those referred to, which are limited to certain kinds of traffic, adapted to the special construction of these engines, how much more will the same type be valued when it is suited to every service, by being perfectly interchangeable, with full range of performance, either as simple or compound.

Your committee recognizes the fact of greater value in accomplished results by the manufacture and completion for active service of any machine.

An inventor, who, after conception of his scheme, builds it, puts it into service and proves it to have commercial value, is entitled to advanced credit at our hands for having done more than merely invent and patent.

We make this statement here because we find on investigation that not

one-half the number of compound locomotives, which have been patented and described have ever advanced beyond the patent record and not one-quarter of them are placed upon the roads in service. Many of us know by experience that some patented machines are not even well begun with the issue of the patent.

During that noted controversy upon the discovery of the expansion of steam in Watt's time, a writer said: "Of two discoverers of the same principle, that one should have the merit, who first makes it known to the public."

To this type of expression, may be justly added: A large need of praise and right-of-way belongs to the party who harnesses a discovery by whomsoever made and puts it under full control to do our bidding. Nor should the mere patented or other existence of any invention in one original form (which may yet be within experimental limits), forbid the use of its like conceived by another although in modified form, when the same has been adapted and carefully fitted to new working conditions. In this the last shall be first by merit.

"The conditions on which the expansive working of steam in locomotives may be carried out with efficiency and success were stated by Mr. D. K. Clark, as early as 1852, in *Proc. Inst. M. E.*, for that year and briefly are as follows:

(1) The condition is to perfectly protect the cylinders.

(2) The combination of a sufficiently high boiler pressure of steam, (say) 150 pounds per square inch, with suitable proportions of cylinder and driving wheel, to admit of highly expansive working consistent with the required duty of the engine.

(3) The cylinder should be arranged to have the shortest practicable steam-way, and the valves should be relieved of pressure.

From Mr. D. K. Clark's latest, most elegant and comprehensive work on *The Steam Engine*, London, 1890, vol. iv, p. 603, we make a few extracts, which, on perusal, will be found to emphasize much that we have already said upon the compound locomotive.

"M. Anatole Mallet had early prepared designs for compound locomotives, in which one of the cylinders was made larger than the other; and in the beginning of 1876, an order was given for three of them. They were four-coupled six-wheel tank-engines, with two outside cylinders, 9·45 inches and 15·75 inches in diameter, with a common stroke of 17·72 inches, having areas in the ratio of 1 to 2·78. The working pressure in the boiler was 150 pounds per square inch."

"The 'starting slide valve' was fixed on the smoke-box, by means of which the steam from the first cylinder might, at starting, be exhausted direct into the atmosphere, while steam from the boiler was admitted direct into the second cylinder, sufficiently wire-drawn to avoid an excessive difference of power between the two cylinders. When the valve was shifted into the opposite position the steam from the first cylinder was exhausted to the second cylinder. The engines were first tried in July, 1876; they made steam in abundance, and worked with perfect steadiness."

See Mallet's paper "On the Compounding of Locomotive Engines," in the *Proc. Inst. Mech Engineers*, London, June, 1879, p. 328.

To M. Anatole Mallet belongs the credit of first realizing the necessity of equalizing the total pressure of the steam in each cylinder of a compound locomotive engine, especially in those of a large size.

In his paper he describes "a *self-acting reducing valve*, whereby the steam pressure admitted to the large cylinder when working direct is reduced so as never to exceed a certain limit bearing a constant proportion to the boiler pressure."

This valve consists of "a piston having a rod of large diameter, which passes out through a stuffing-box at the back end and has no external attachment." The piston acts as a stop-valve sliding over a port at the back end," which opens and *partially closes* before and after the admitted steam to the starting-valve chamber. This valve was not provided with any means whereby its motions would be controlled, and, therefore, was liable to breakage from violent slamming, which was proven to be the case on the first trials of those made, the record of which appears in his paper on this subject.

We find no reference of attempts to improve or continue the use of this type of valve.

"Mr. A. Borodine, Chief Engineer of the Southwestern Railway of Russia, made comparative trials of a compound passenger locomotive on the Mallet system and an ordinary locomotive. The engines were identical, except the cylinders; they were tried on a section ninety-seven and one-half miles long, in the month of May, 1881. The results of twelve double-trips show an economy of steam of from four to eight per cent.; and of fuel, of from fifteen to eighteen per cent." "In July, 1881, the two engines took goods trains exactly alike, one to each, one after the other, at speeds considerably lower than those of the passenger trains, showing an economy of thirty per cent. in the consumption of steam by the compound engine and of twenty per cent. of fuel." "Further, experiments with these engines showed an economy of fuel of twenty per cent., with 2·5 expansions of the steam and thirty-two per cent. with 4·8 expansions." See *Proc. Inst. M. E.*, London, 1886, p. 297.

Mr. Clark devotes one chapter to a discussion of the Von Borries outside cylinder compound locomotive, in which he concludes: "Compared with ordinary engines of like dimensions, working on the same lines and taking the same trains, the compound locomotives effect an economy of from 14·3 to twenty-one per cent. of fuel." See *Engineering*, April 30, 1886, p. 434.

In his next chapter Mr. Clark says: "Mr. T. W. Worsdell, in 1885, designed and constructed his first compound passenger locomotive for the Great Eastern Railway, in which two cylinders were employed, placed side by side, between the side plates. The cylinders are eighteen and twenty-six inches diameter, twenty-four inches stroke, working to the crank-axle in the usual manner; the capacity-ratio of the cylinders is 1 to 2·09. The engine fitted with Joy's valve-gear and steam could be turned on direct to the second cylinder when required for starting."

The performance May 21, 1886, showed "a reduction of thirteen per cent. on the ordinary consumption."

"In January and February, 1888, comparative trials of compound and ordinary passenger locomotives were made on the Northeastern Railway, which proved a saving by compound engine of twenty-one and one-half per cent."

"In the year 1886–87, the comparative consumption of coal, by compound and ordinary goods engines working heavy express trains, was for ten engines each, and making a total run of 186,000 miles, a saving of fourteen and one-half per cent."

"There are now (April, 1890), about 600 compound locomotives on the Worsdell and Von Borries system, of which there are 120 on the Northeastern Railway. The average results of twelve months' working of these 120 engines, compared with the non-compound engines on the railway, drawing the same trains, 150 tons weight, show an economy of twenty-two per cent. of coal."

Mr. Thomas Urquhart, on Railway in Southeast Russia, has ascertained an average economy of eighteen and one-half per cent. of petroleum refuse in the performance of twelve compound goods engines and three compound passenger engines, as against non-compound. The capacity of the receiver between the first and second cylinders, has been successively increased from equality to the volume of the first cylinder to 1·3 and 1·8 times, with marked advantage. The pressure in the second cylinder does not drop so fast with the larger receiver." See *Proc. Inst., M. E.* London, 1890.

The early state of the art shows that ordinary cocks and slide and other forms of valves operated by the engineer have been used for admitting steam to the low-pressure cylinder directly from the boiler for starting the engine, to be operated again by the engineer, changing the engine to compound running when the extra resistance is overcome, some having independent escape to the atmosphere for the high-pressure cylinder, and some have closed exhaust chambers.

The *advanced state of the art* exhibits the use of valves in the high-pressure cylinder exhaust pipe or receiver, which are worked by steam automatically or otherwise.

The greater number of these valves are opened automatically by the high-pressure cylinder exhaust steam when its accumulated pressure exceeds that of the admitted wire-drawn live steam to the low-pressure steam chest. These are called intercepting valves, and no means are provided for holding them shut for continued simple running.

Your committee plainly sees that any engine, exhausting into a closed chamber must weaken after the first revolution, and must gradually cease to have power if this process continues, and that this effect happens just at the time when the greatest power is needed; and again when this chamber gets relief, the engine at once ceases to be a simple engine, and goes into compound working. If the engine has not got under way by this time, it must balk and simple running be tried over again.

In the specification of F. W. Dean (U. S. Patent, Sept. 22, 1891) mention is made of the fact of accumulated pressure in the high-pressure exhaust passage, and the necessity of relieving the same. It is also stated: "The intercepting valve opens in advance of an accumulated back-pressure on the high-pressure cylinder," so it appears that some inventors recognize this fact of back-pressure where and when it is not wanted.

The *perfected state of the art* must exhibit a two-cylinder compound locomotive engine whose mechanism is simplest in form and number of working parts, and whose steam ways are most uniform in section and most direct in course from boiler to the point of application.

In so far as your committee has ascertained from every reliable source at its command, the mechanism devised by Mr. C. H. Batchellor practically fulfils this requirement.

In this engine we have all the necessary devices by which a locomotive may be run at any time and at any place on the road and for any length of time demanded by the service, as a simple engine; each cylinder doing exactly half the work, whatever that may be, and without waste of steam.

In addition to this, at the will of the engineer and at any time he chooses to exercise it, according to the conditions of running, he changes his engine into compound working, permitting it to operate thus as long as circumstances will warrant, and then he changes it back again at once into simple working. These changes are made as easily as the engineer turns his hand to open or close *one* valve, by a handy lever in his cab, and he does this when the engine is standing or running.

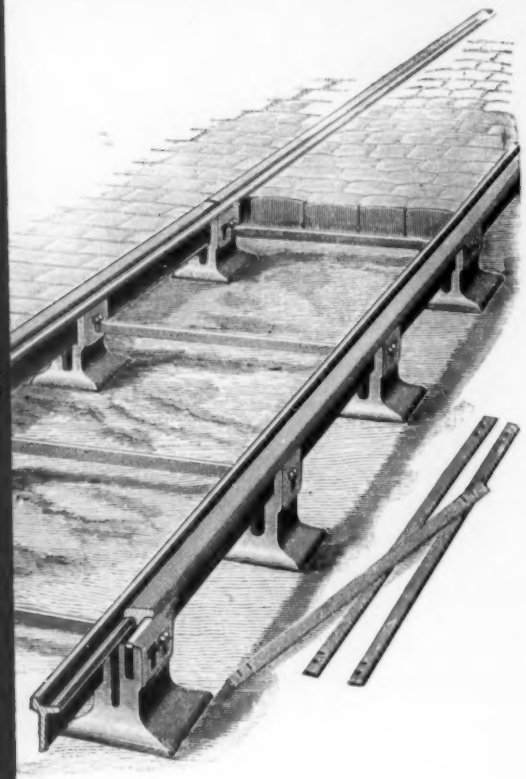

FIG. 1.

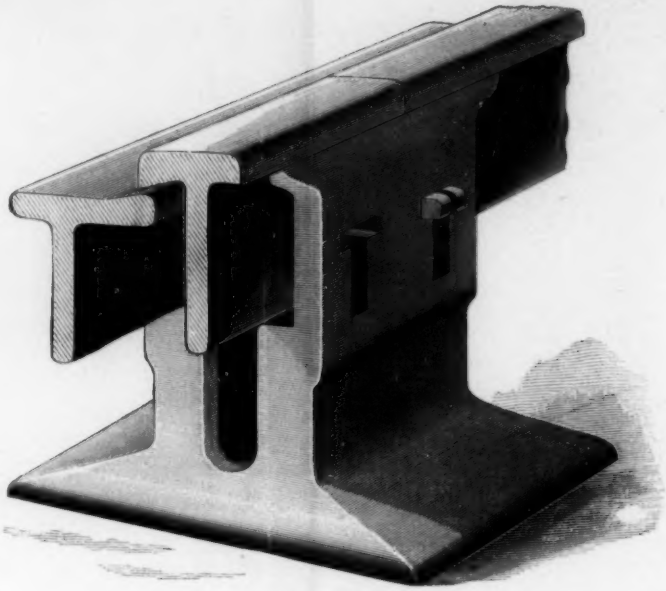

FIG. 2.

FIG. 1.—Gibbon duplex rail construction.
" 2.—Joint-chair and rail.
" 3.—Duplex rail.
" 4.—Cross-section at chair.
" 5.—Longitudinal section at joint.
" 6.—Tie-bar.
" 7.—Wedge-key.

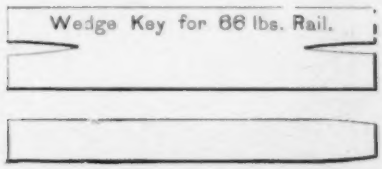

FIG. 7.

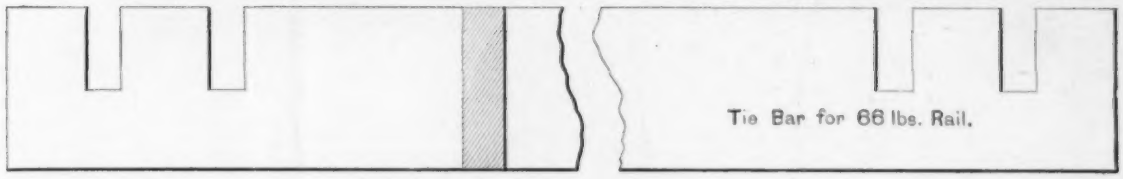

FIG. 6.

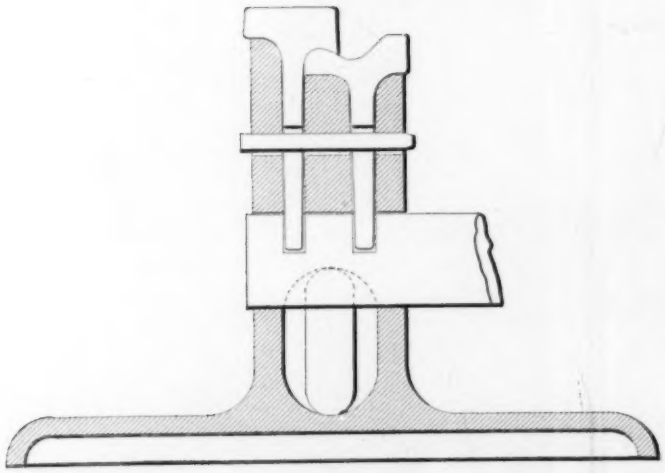

FIG. 4.

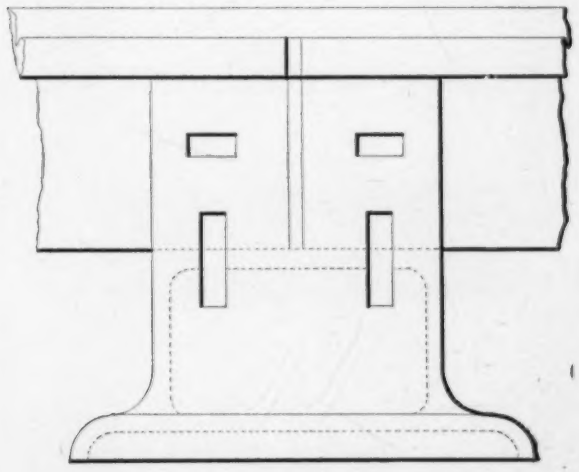

FIG. 5.

THE GIBBON DUPLEX STREET RAILWAY TRACK.

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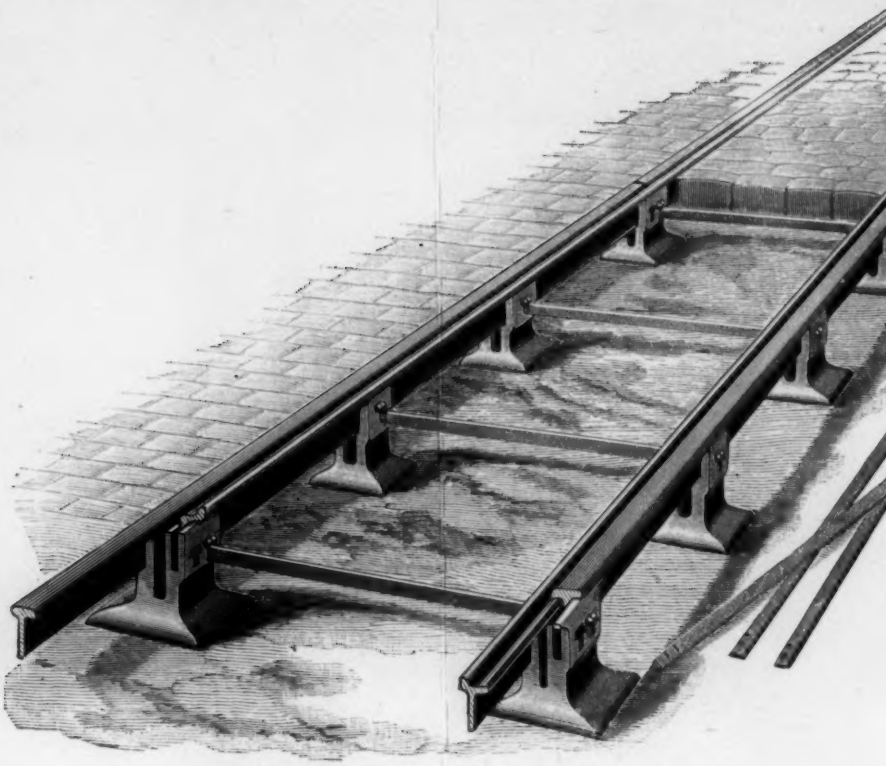


FIG. 1.

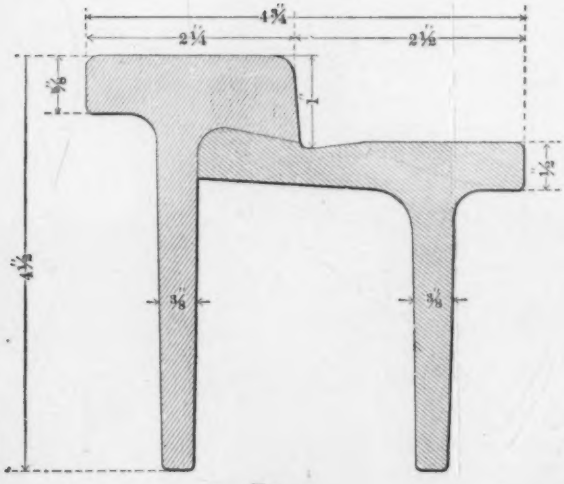


FIG. 3.

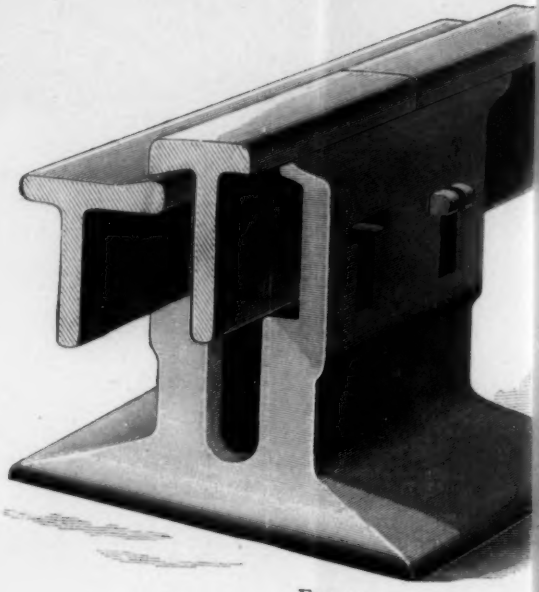
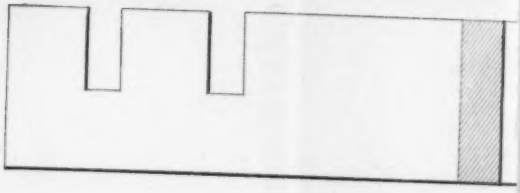


FIG. 2.



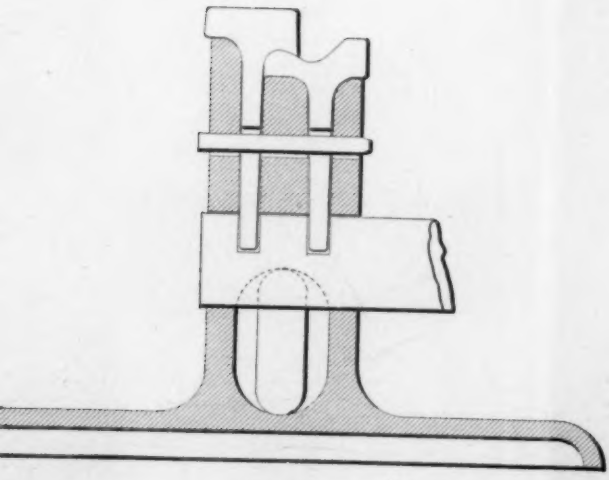


FIG. 4.

THE GIBBON DUPLEX STREET RAILWAY TRACK.

THE GIBBON DUPLEX STREET RAILWAY TRACK IN COURSE OF CONSTRUCTION.